



INSTRUCTION MANUAL
WAVE/DISTORTION ANALYZER
Model 110

PRINCETON APPLIED RESEARCH CORPORATION

PRINCETON, NEW JERSEY



INSTRUCTION MANUAL
WAVE/DISTORTION ANALYZER
Model 110

THIS MANUAL APPLIES SPECIFICALLY TO MODEL 110 SERIAL NO. 1416

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 3. Your address.
 4. Address to which instrument should be returned.
 5. Your telephone number and extension.
 6. Symptoms (in detail, including panel settings).
 7. Your purchase order number for repair charges (does not apply to repairs in warranty).
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SECTION I CHARACTERISTICS

1.1 INTRODUCTION

The PARTM Model 110 Wave/Distortion Analyzer is a laboratory instrument capable of operation as a variable frequency tuned amplifier or as an oscillator, the frequency range in both cases being from 1 Hz to 110 kHz.

As an amplifier, the instrument is exceptionally versatile. Following amplification ($\times 1$ to $\times 10^4$ provided), the input signal is processed in four different ways simultaneously and the resulting four outputs are continuously available at the front panel. The first of these is the "NOTCH" output, obtained by removing any components of the input signal at the tuned frequency. The second, or "RESONANCE" output, is the output of a variable Q electronic filter having a transmission of one at the resonant frequency and a rejection in excess of 80 dB at frequencies far from resonance. At the third or "ALL-PASS" output, all frequency components of the input signal retain their original amplitudes; the instrument operates on phase only. Input frequency components far below the tuned frequency undergo no phase shift. Components at the tuned frequency are phase shifted 180° , and components far above the tuned frequency undergo a 360° phase shift. Near the tuned frequency, the slope of the phase shift versus frequency function is determined by Q. Fourth and last is the "FLAT" or untuned output, simply an amplified replica of the input signal.

Precision AC monitoring circuitry allows any of the four output levels to be indicated on a front panel meter. In effect, this circuitry allows the Model 110 to function as an average responding, rms calibrated, AC voltmeter of exceptional sensitivity and selectivity. A linear DC analog output enables any of the four outputs to be recorded with a strip chart recorder.

Other uses for the Model 110, when operating as a frequency selective amplifier, include use as a wave analyzer with bandwidth adjustable from 1% to 100%, and as a distortion analyzer capable of measuring distortion levels as low as 0.1% (as low as 0.001% when used in conjunction with another Model 110 or a PAR Lock-In Amplifier). As a general purpose laboratory oscillator, the instrument provides up to 5 V rms into 600 ohms and it can be synchronized by an external signal.

Featuring high gain, low noise, unusual versatility, and low distortion, the PAR Model 110 Wave/Distortion Analyzer should find general application as a laboratory instrument of exceptional precision and utility.

*PAR is a trademark of Princeton Applied Research Corporation.

1.2 SPECIFICATIONS (based on operation with a Q of 10 unless otherwise noted)

TUNED AMPLIFIER SPECIFICATIONS

(1) FREQUENCY RANGE

1.0 Hz to 110 kHz in five bands. Within each band, the frequency is selected by three decade switches and a continuously variable vernier control.

(2) FREQUENCY ACCURACY

$\pm 1\%$ of the set frequency from 5 Hz to 50 kHz; $\pm 2\%$ of the set frequency from 1 Hz to 5 Hz and from 50 kHz to 110 kHz.

(3) FREQUENCY STABILITY

Typically $\pm 0.02\%$ per degree Celsius; typically $\pm 0.02\%$ per 24 hours at constant ambient temperature.

(4) INPUT IMPEDANCE

10 megohms shunted by 10 pF.

(5) INPUT STAGE NOISE

Preamplifier noise figure at 1 kHz working from a 100 k Ω source resistance shall be less than 1 dB. For more information see "SMALL SIGNAL AMPLIFICATION", page III-10.

(6) Q RANGE

The selectivity or Q of the three frequency selective outputs is adjustable from 1.0 to 100 in 1, 2, 5 sequence. Q values in excess of 100 can be achieved by adjusting the front panel "SET NOTCH" Control.

(7) Q ACCURACY

A function of Q and tuned frequency as indicated below.

Q	ACCURACY
1 -----	5%
2 -----	5%
5 -----	5%
10 -----	1% below 50 kHz and 3% from 50 kHz to 110 kHz.
20 -----	5%
50 -----	10% below 50 kHz and 20% from 50 kHz to 110 kHz.
100 -----	20% below 20 kHz and 35% from 20 kHz to 110 kHz.

Table I-1. Q ACCURACY

(8) GAIN

Calibrated at 1, 2, 5 multiples from 1 to 10,000. Vernier provides uncalibrated but continuously variable gain over the entire range. Additional information provided under "OUTPUTS".

(9) OUTPUTS

Four simultaneous outputs are provided at 600 ohms. Each is capable of providing five volts rms into 5 k Ω . The four outputs are as follows.

FLAT

Flat frequency response from 0.5 Hz to 200 kHz. Gain accuracy is ± 1 dB from 2 Hz to 110 kHz, and ± 3 dB from 0.5 Hz to 2 Hz and from 110 kHz to 200 kHz. Total harmonic distortion at full output is less than 0.1%. With less than 1 V rms out, the distortion is less than 0.01%.

RESONANCE

At the set frequency, the selected gain is obtained independent of the Q (Set Notch properly adjusted). Away from resonance the gain is determined by Q and the ratio of the input frequency to the tuned frequency. The voltage gain versus frequency function exhibits a second order bandpass characteristic and can be described by the "Universal Resonance Equation" (Figure IV-2, page IV-4). The 3 dB bandwidth equals the set frequency divided by Q. Far from resonance, rejection exceeds 80 dB, and the asymptotic slope is 6 dB per octave regardless of Q. Gain accuracy (Q of 10) is ± 0.5 dB from 2 Hz to 50 kHz, and ± 2 dB from 1 Hz to 2 Hz and from 50 kHz to 110 kHz. Total harmonic distortion at full output is less than 0.1%. With less than 1 V rms out, the distortion is less than 0.01%.

NOTCH

The gain at the set frequency, regardless of the Q setting (Set Notch properly adjusted), is at least 100 dB down from the selected gain. The voltage gain versus frequency function (Figure III-4, page III-8) exhibits a second order band-reject characteristic, and the 3 dB bandwidth (measured between opposite shoulders of the notch) is equal to the set frequency divided by Q. Total harmonic distortion (indicated distortion of a pure sinusoid at the set frequency) is less than 0.1% with full scale output at the Resonance Output. If the resonance output is less than 1 V rms, the indicated harmonic distortion at the Notch Output will be less than 0.01%.

ALLPASS

The selected gain is obtained for all frequencies (gain accuracy relative to Q and frequency same as for Resonance Output). The phase versus frequency function (Figure III-6, page III-11) exhibits a sec-

ond order allpass characteristic; the output is in phase with the input for frequencies well below the set frequency, lags the input by 180° at the set frequency, and lags the input by 360° well above the set frequency. The bandwidth measured between the $\phi = 90^\circ$ and $\phi = 270^\circ$ frequencies equals the set frequency divided by Q. In other words, the "steepness" of the phase transition in the vicinity of the set frequency is determined by the setting of the Q control.

OSCILLATOR SPECIFICATIONS

The unit can function as a sine wave oscillator (not simultaneously with selective amplifier operation) over the frequency range of 1 Hz to 110 kHz with the following characteristics.

(1) FREQUENCY RANGE, ACCURACY, AND STABILITY

Same as for Tuned Amplifier Specifications

(2) OUTPUT IMPEDANCE

600 ohms

(3) OUTPUT LEVEL

Maximum output is 5 V rms into 600 ohms (10 V rms into an open circuit). A combination step/vernier attenuator (1% accurate) provides output ranges of 0-5 mV, 0-500 mV, and 0-5 V rms.

(4) OUTPUT LEVEL STABILITY

.02% per degree Celsius

(5) OUTPUT DISPLAY

The AC voltmeter (panel meter) indicates the oscillator output, with full scale meter indication corresponding to the maximum output into a 600 ohm load as determined by the step attenuator.

(6) SYNCHRONIZATION

The oscillator can be synchronized by applying an external signal to the Input Jack. The hold-in range is approximately $\pm 0.3\%$ of the set frequency. The entire preamplifier gain (10^4) is available for locking the oscillator to low level signals.

(7) DISTORTION

As indicated in Figure I-1.

AC VOLTMETER SPECIFICATIONS

An AC voltmeter is provided for monitoring any one of the four selective am-

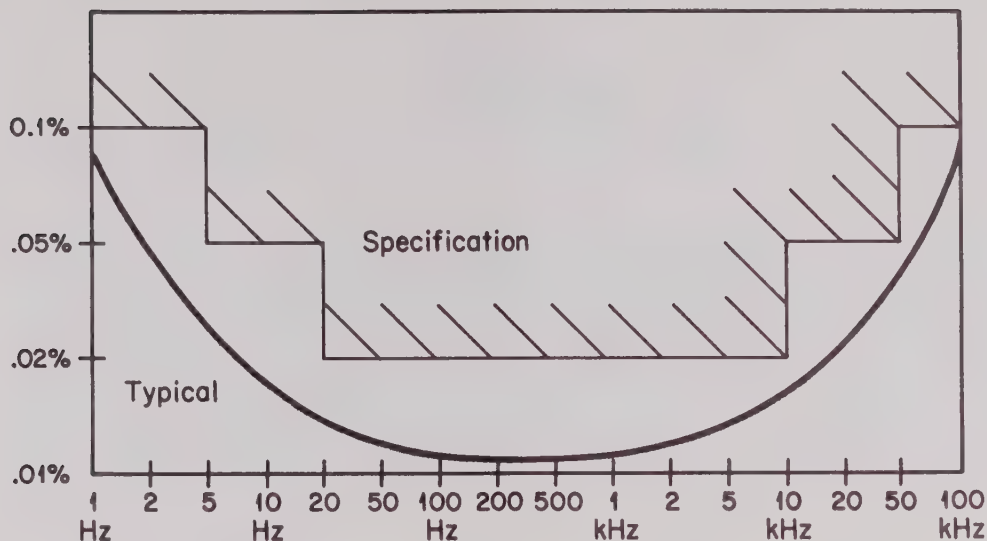


Figure I-1. OSCILLATOR DISTORTION VERSUS FREQUENCY

plifier outputs or the oscillator output. The voltmeter circuit responds to the average of the full-wave rectified waveform and is calibrated in terms of rms (sine wave). Sensitivity is 100 mV to 5 V rms full scale in 1, 2, 5 sequence, permitting the instrument to be used as a frequency selective voltmeter or wave analyzer with a sensitivity range of 10 microvolts to 5 V rms full scale. The meter accuracy is $\pm 3\%$ of full scale.

OTHER

(1) DC METER ANALOG

A zero-to-one volt linear (1% of full scale) meter analog output, suitable for driving a recorder or other readout device, is supplied to a rear panel binding post at an impedance of two kilohms. A second binding post, which is grounded, is spaced $3/4$ inch away to facilitate use of a standard double-banana connector.

(2) INTERFACE CONNECTOR

A connector at the rear of the instrument permits powering the unit from external batteries. These batteries should be able to supply 300 mA at both plus and minus 30 V. Plus and minus 24 V (each at 50 mA) are provided at this connector to power auxiliary equipment when the unit is operating from AC line voltage.

(3) POWER REQUIREMENTS

105-125 Vac, or 210-250 Vac, 50-60 Hz, 12 watts.

SECTION II INITIAL CHECKS

2.1 INTRODUCTION

The following paragraphs are provided to facilitate performance checking of the Model 110. In general, the following procedure should be performed after inspecting the instrument for shipping damage (any noted to be reported to the carrier and to Princeton Applied Research Corporation), but before using it experimentally. This procedure presupposes no knowledge of the Model 110 on the part of the inspector. Consequently, the checks should be performed in sequence if the indicated results are to be obtained. Should any difficulty be encountered in carrying out these checks, contact the factory or one of its authorized representatives, a list of whom appears at the end of the manual.

2.2 EQUIPMENT NEEDED

- (1) General purpose oscilloscope with a 1 kHz calibrator providing 5% accurate 1 mV, 2 V, and 10 V peak-to-peak square waves. Recommended type - TEKTRONIX type 502A.
- (2) Two coaxial cables, suitable for interconnecting the Model 110 and the oscilloscope.

2.3 PRELIMINARY STEPS

Plug in the line cord and turn the instrument on. The pilot light which illuminates the panel meter should come on. The meter indication may be either on or off scale, depending on the settings of the front panel controls.

2.4 PREAMPLIFIER CHECK

- (1) Set the front panel controls as follows.

Gain -----	1
Gain Vernier -----	CAL.
Q -----	10
Amplifier Monitor Select Switch -----	OFF
Amplifier Monitor Full Scale	
Selector -----	5V
Oscillator -----	5V
Oscillator Amplitude Vernier -----	Fully clockwise

- (2) Connect the 10 volt peak-to-peak oscilloscope calibrator output to the Model 110 input.
- (3) Connect the "FLAT" Output of the Model 110 to the oscilloscope signal input and check for a 10 V peak-to-peak square wave.
- (4) Set the calibrator output to 1 mV and the Model 110 Gain to "10 k".
- (5) Again check for a 10 V peak-to-peak square wave. A small amount of

noise normally appears with a gain of 10,000.

- (6) Turn the Gain Vernier fully counter-clockwise. Observe that the amplitude of the observed square wave decreases to approximately four volts peak-to-peak.
- (7) Return the Gain Vernier to "CAL."

2.5 METER CHECK

- (1) Set the Gain Selector to "1", the Amplifier Monitor Select Switch to "F" and the Amplifier Monitor Full Scale Switch to 2 V.
- (2) Set the Oscilloscope Calibrator Selector for 2 V peak-to-peak out.
- (3) Observe that the meter indication is $1.1 \text{ V} \pm .1 \text{ V}$.

2.6 SELECTIVE AMPLIFIER AND RELATED OUTPUT CHECKS

- (1) Connect the oscilloscope signal input to the Resonance Output.
- (2) Tune the Model 110 frequency controls for a sine wave of maximum amplitude as observed at the oscilloscope. The final setting will be anywhere between 800 Hz and 1200 Hz, depending on the frequency accuracy of the oscilloscope calibrator output.
- (3) Check that the amplitude of the observed sine wave is about 2.5 V peak-to-peak.
- (4) Connect the oscilloscope to the allpass output and observe that the oscilloscope display is as indicated in Figure II-1.

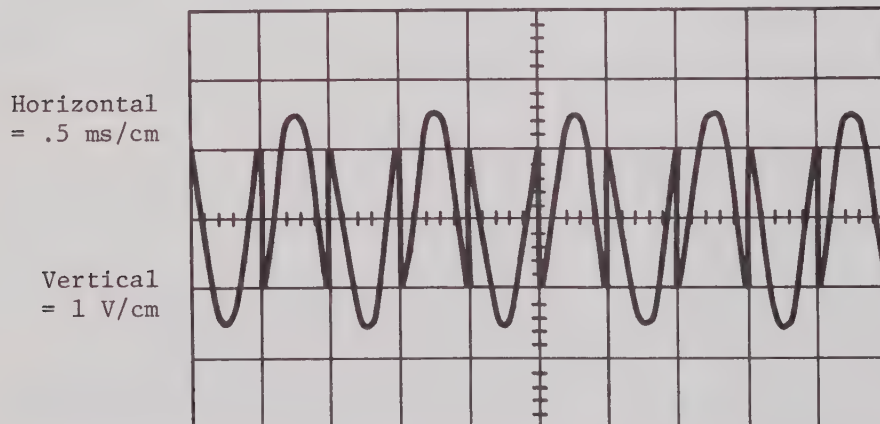


Figure II-1. ALLPASS OUTPUT WITH SQUARE WAVE IN

- (5) Connect the oscilloscope to the Notch output and observe that the oscilloscope display is as indicated in Figure II-2.

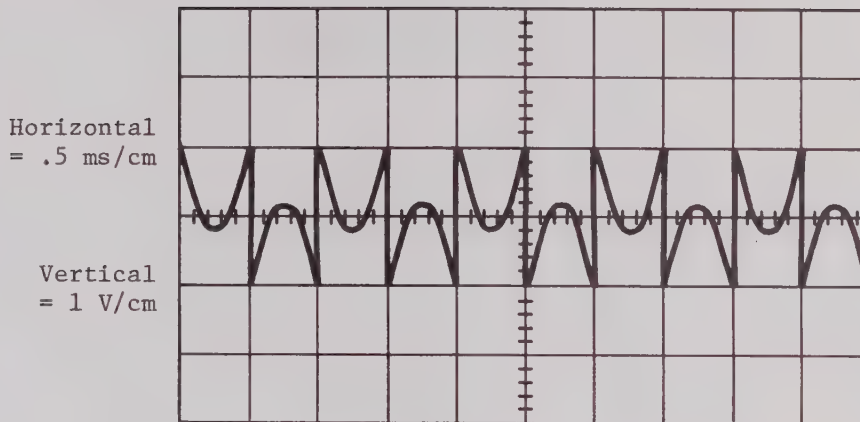


Figure II-2. NOTCH OUTPUT WITH SQUARE WAVE IN

2.7 OSCILLATOR CHECK

- (1) Select "OSC." with the Q Selector Switch.
- (2) Connect the oscilloscope to the Model 110 oscillator output and check for a 28 V peak-to-peak sine wave at the tuned frequency.
- (3) Check that the meter indicates full scale (-0% +3%).
- (4) Adjust the red Oscillator Amplitude Control for a 90% of full scale meter indication.
- (5) Verify with the oscilloscope that the oscillation frequency tracks changes in the setting of the tuning dials, and that the amplitude, as indicated by the panel meter, changes no more than plus or minus three percent from 5 Hz to 110 kHz.

THIS COMPLETES THE INITIAL CHECKS. IF THE MODEL 110 PERFORMED AS INDICATED, ONE CAN BE REASONABLY SURE THAT THE INSTRUMENT IS OPERATING PROPERLY.

SECTION III OPERATING INSTRUCTIONS

3.1 INTRODUCTION

The PAR Model 110 Wave/Distortion Analyzer is a general purpose laboratory instrument of exceptional precision and utility. Use of the instrument is unusually straightforward and simple, even in those applications where exacting performance is required. Beginning with some preliminary considerations such as power and cooling requirements, this section of the manual deals with matters appropriate to obtaining most effective use of the instrument. Among the topics considered are use as a tuned amplifier, as a frequency selective voltmeter, as a distortion analyzer, and as a wave analyzer. Figure III-1, a photograph of the instrument, is provided as a reference.

3.2 PRELIMINARY CONSIDERATIONS

INSTALLATION

The Model 110 Wave/Distortion Analyzer can be either bench or rack mounted, and if rack mounted, can be equipped with "slides" to facilitate moving the instrument in and out of the rack. Suitable hardware can be purchased from:

JONATHAN MANUFACTURING COMPANY
1258 TEANECK ROAD
TEANECK, NEW JERSEY

To slide mount the Model 110, the following parts or their equivalents are required.

QUANTITY	ITEM
1 pair -----	STEEL BALL BEARING SLIDE, QUICK DISCONNECT, PART NUMBER 110 QD-14-1 or 110 QD-16-1 (the "14" and "16" refer to the length of the slide in inches).
4 -----	MOUNTING BRACKET, PART NUMBER SP-0440

The instrument is supplied with the slide mounting holes already drilled in the sides. To gain access to these holes and mount the slides, it is first necessary to remove the side covers, which slide off once the top and bottom covers are removed. The top cover slides free after removing the two screws located under the top cover "lip" at the rear of the instrument. The bottom cover slides free after removing the two rear bumper feet, each of which is held in place by a single screw. To mount the slides, use 7/32", 10-32, nickel-plated steel, round-head or pan-head screws.

POWER REQUIREMENTS

The Model 110 operates from either 105-125 or 210-250 V ac, 50-60 Hz, and requires about 12 watts of power. Changeover from one operating voltage to the other is accomplished by actuating the Line Voltage Selector Switch, which is



Figure III-1. MODEL 110 TUNED AMPLIFIER/OSCILLATOR

located inside near the power transformer. For operation from 105-125 Vac, "115" should show in the switch "window". For operation from 210-250 Vac, "230" should show. NOTE: To gain access to the Line Voltage Selector Switch, slide back the top cover after first removing the two screws from under the rear edge thereof.

FUSING

A slo-blo 4/10 ampere fuse located at the rear panel is electrically in series with the primary winding of the power transformer. Two additional 3/8 ampere fast-blo fuses, located internally, protect the +24 and -24 Volt regulators.

WARM-UP PERIOD

For most applications, none. In those applications where the 0.02% per degree Celsius temperature coefficient can be significant, allow one hour for the Model 110 to come to temperature equilibrium.

TEMPERATURE RANGE

Operating ambient temperature range is 10°C to 45°C (50°F to 113°F).

INPUT OVERLOAD VOLTAGE LIMITS

The signal applied to the Input Jack should not exceed 7.5/G volts peak, where "G" is the selected gain (7.07/G volts peak sine-wave input yields full scale output). Expressed in terms of the output, the signal level at the input should never cause the output voltage to exceed plus or minus 7.5 volts with respect to ground. As a result of the low frequency response of the Model 110, the instrument requires five or six seconds to recover from a severe overload or transient, such as is incurred when the instrument is first turned on.

INPUT DC VOLTAGE LIMIT

±200 V.

3.3 OPERATION AS A "FLAT" AMPLIFIER

Of the various uses to which the instrument can be put, the simplest is as an amplifier with a flat (±1 dB) frequency response from 2 Hz to 110 kHz (see "FLAT", page I-3). To operate the instrument as a flat amplifier, only two controls need be considered. Those are the dual-concentric "GAIN" Control and the "Q" Selector Switch. This latter switch, in addition to determining the tuned amplifier Q, acts as a Mode Switch as well. If the voltmeter feature of the instrument is to be utilized to measure the amplified signal, the two Amplifier Monitor Switches must also be taken into account.

Note that the Gain Control is dual-concentric; there is an outer black gain selector switch, and an inner red vernier. When the vernier is fully clockwise ("CAL."), an input signal applied to the "INPUT" Jack is amplified as indicated by the position of the Gain Selector. The amplified signal is

available at the "FLAT" Output Jack. When the vernier is not fully clockwise, the gain is less, the range of the vernier being sufficient to overlap ranges. There is one exception. If the outer selector is set to "1", the vernier has no effect.

The recommended Q setting in flat amplifier operation is "1". In no case should the Q selector be set to "SYNC. OSC.", "OSC.", or "SET NOTCH". Setting the Q selector to any of these positions transfers the instrument to oscillator operation.

To measure the amplitude of the amplified signal with the internal voltmeter, set the Amplifier Monitor Select Switch to "F" (Flat) and select that range of the Amplifier Monitor Full Scale Switch which yields the highest "on-scale" indication. Note that the meter is calibrated in rms. Although the meter actually "sees" the rectified average value, the rms value will be indicated if the input waveform is a sine wave. If the input signal is other than a sine wave, the meter scale conversion factor will be incorrect, because the ratio of rectified average to rms value will be different, and a true rms meter must be used to determine the rms value. The meter indicates the open circuit output level. When a load is connected (providing the load impedance is no lower than 5 k), the meter indication does not change, even though the signal level at the output jack does change due to drop across the 600 ohm output impedance.

Should long term amplitude variations be of interest, one can drive a recorder from the Meter Analog Voltage available at the rear panel red binding post at an impedance of two kilohms. The associated black binding post is grounded. The two binding posts are spaced 3/4 inch apart to accept a standard double-banana connector.

3.4 OPERATION AS A TUNED AMPLIFIER

Operation as a tuned amplifier basically differs from flat amplifier operation in that only the component of the input signal at the set frequency will be amplified to the degree indicated by the setting of the Gain Control and made available at the Resonance Output Jack. All other frequency components will be amplified less, how much less depending on the Q and on the interval between the frequency considered and the set frequency. Figure III-2 shows the resonance amplitude response and Figure III-3 shows the resonance phase response. Both curves are shown as functions of Q and "normalized" frequency (f/f_0 , where f is the frequency of interest and f_0 is the set frequency).

To operate the instrument as a tuned amplifier, one might proceed as follows.

- (1) Select the gain setting appropriate to the signal amplitude.
- (2) Select a good "working value" of Q. A Q of ten is generally satisfactory.
- (3) Connect the input signal.
- (4) Rough-tune the instrument to the input frequency.

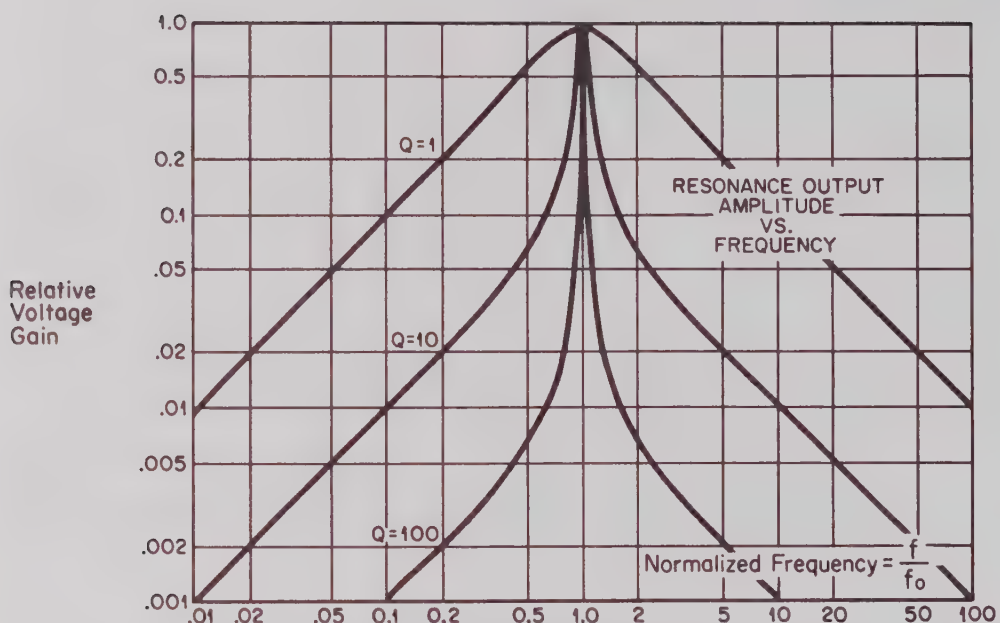


Figure III-2. RESONANCE OUTPUT RESPONSE CURVES

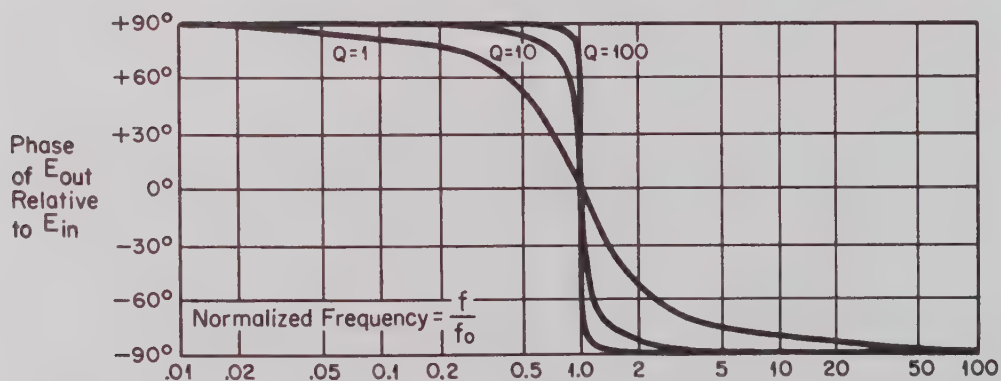


Figure III-3. RESONANCE OUTPUT PHASE VERSUS FREQUENCY

(5) Optimize the setting of the "SET NOTCH" Control.

(6) Fine-tune the instrument, increasing the Q as necessary to obtain as sharp a resonance peak as required.

Assuming the desired gain has been selected, the Q Selector set to "10", and the input signal connected, the next step is to tune the instrument to the input frequency. Five dials determine the tuned frequency. Four of these are the frequency setting dials and the fifth is the multiplier. The tuned frequency is the product of the frequency selected with the upper four dials times the multiplication factor selected with the lower dial. Of the four upper dials, the first three allow "step-selection", while the fourth is continuously adjustable, with a range of ± 3 digits of the third dial.

Locating the resonance peak settings of the tuning dials requires that the amplifier output be monitored. Two easily applicable methods are: (1) to monitor the output with the internal AC Voltmeter, and (2) to monitor the output with an oscilloscope. To tune the instrument using the internal metering circuit, set the Amplifier Monitor Select Switch to "R" (Resonance) and adjust the tuning dials for peak indication on the panel meter. Select that range of the Amplifier Monitor Full Scale Switch which yields the highest on-scale reading. To tune with an oscilloscope, monitor the Resonance Output Jack with the oscilloscope and tune for maximum observed signal. At a Q of ten, it is easy to set the frequency to three places, although a two-place setting is sufficient for rough tuning.

After initial tuning, adjust the Set Notch Control. The procedure to follow in setting the notch depends on the setting of the Frequency Multiplier. On all but the highest ("X10K") setting, the Set Notch Control is adjusted for maximum stability of the meter indication with the Q Selector set to "SET NOTCH". When the Q Selector Switch is set to "SET NOTCH", the Amplifier Monitor Select and Full Scale Switches no longer have any effect; the meter indication becomes a function of the Set Notch Control alone. Learning to adjust the control quickly and accurately requires a bit of practice. If the control is too far clockwise, the meter indication increases at an accelerating rate. If it is too far counter-clockwise, it decreases at a decelerating rate. When properly adjusted, the reading will be reasonably stable, but the attainable stability is a function of the selected frequency. At low frequency settings (Multiplier to "X1" or "X10"), midscale indications should drift no more than 5% of full scale in 30 seconds. With the Multiplier set to "X1K", the best achievable drift rate may be 10% per second for a midscale indication.

Realize, however, that no amount of adjusting will ever result in an absolutely stable indication, but if one adjusts to within the resolution limits of the control, the Gain and Q will be well within the specified limits.

Note from the Q Accuracy Specification (page I-2) that Q accuracy is a function of tuned frequency. Because Q directly affects gain, a gain error proportional to the Q change takes place. This error can be significant at high frequencies. When one intends to operate in the highest frequency range, the Set Notch Adjustment should be made at the intended operating frequency to retain Q and Gain accuracy.

When the Frequency Multiplier is set to "X10K", a different adjusting technique applies. Assuming one begins with the control adjusted too far counter-clockwise, the proper procedure is to adjust the control clockwise until the meter indication suddenly "snaps" off scale to the right. The setting which causes the "snap" is the proper one. If overadjustment is suspected, the control must be turned a quarter turn or more counter-clockwise to obtain an on-scale meter indication before trying again.

The Set Notch Adjustment itself is reasonably stable, and, providing one does not intend to operate on the higher frequency range, need not be reset for tuned amplifier (Resonance) operation at different Q's and frequencies. If the Q Selector is set to some other position and then returned to the Set Notch position, the panel meter indication will usually exceed full scale. This does not mean that the Set Notch Control is improperly adjusted. If one were to turn it counter-clockwise to bring the indication back on scale, and then readjust according to the previous instructions, the same setting would be obtained again.

Having adjusted the Set Notch Control, the operator is ready to perform final tuning and Q selection. As is readily apparent from Figure III-2, the choice of Q is significant during tuned amplifier operation. Besides the obvious effect on bandwidth (3 dB bandwidth equals set frequency divided by Q), Q affects other important characteristics as well. Among these are gain accuracy, ease of tuning, accuracy of frequency setting, and time constant. Consider briefly how each relates to tuned frequency operation.

The general advantage of tuned amplifier operation over flat amplifier operation is that the narrowed bandwidth allows one to reject unwanted signals at frequencies removed from the frequency of interest. By choosing a high Q, one obtains a narrow bandwidth and greater rejection of the unwanted signals (noise). The higher the Q, the closer the unwanted signals can be to the frequency of interest for a given degree of rejection. Figure III-2 allows one to quickly determine the bandwidth and hence the Q appropriate to a given measurement.

Although the highest calibrated Q is 100, operation at even higher Q's is possible by adjusting the Set Notch Control clockwise from its "proper" position with the Q selector set to 100. As the Set Notch Control is turned clockwise, the Q will rise until finally the amplifier will break into oscillation at the tuned frequency. Q's of several hundred are easily obtained. If great care is used in making the set notch adjustment, Q's of one or two thousand may be obtained. Increasing the Q in this manner changes the gain (selected gain is obtained only with the Set Notch Control properly set). The gain under increased Q conditions varies directly with the Q. Because measuring high Q's is difficult, the increase in gain can be used as an indication of the achieved Q.

For example, if the resonant gain were observed to increase by a factor of two, the Q would be 200.

Three factors which tend to discourage routine high Q operation are: (1) the increased "touchiness" of tuning, (2) the degraded gain stability, and, (3) the increased time constant of the tuned circuits. During rough tuning at a

Q of ten, the effect of the fourth tuning dial is scarcely perceptible. But at a Q of 100, the fourth dial setting becomes critical, particularly if the left-most tuning dial is set to one of the lower digits. Gain accuracy specifications for the instrument are based on measurements made while operating at a Q of 10. These specifications are degraded proportionally to any increase in Q. Operating at Q's lower than 10 results in some improvement in gain accuracy. However, the improvement is not proportional to the reduction in Q. When operating at low frequencies, the third factor, that of increased time constant, may dictate the highest practically usable Q. During tuned amplifier operation the instrument essentially acts as a parallel tuned circuit. When disturbed, such as when a control setting is changed or a shift in signal level occurs, the Model 110 requires the same time to "adjust" to the new conditions as would the equivalent tuned circuit. A ringing response is set up having a characteristic time constant of $Q/\pi f$ seconds, where Q is that selected and f is the set frequency. Obviously, with high values of Q and low frequencies, response time can be an important consideration.

Low Q operation, in addition to yielding relatively low rejection of unwanted signals, has an additional disadvantage. Because the low Q passband at low and high frequencies overlaps the lower or upper "flat" frequency response of the unit, the difference, at low Q settings, between the input frequency and the set frequency which yields peak output is greater at low and high frequencies than it is at high Q settings. The extreme case in this regard is Q-of-one operation, where the difference may be as great as five or ten percent. However, even this setting error results in an almost imperceptible decrease in resonance output due to the broad response at a Q-of-one. One application where low-Q operation might be advantageous is where the frequency of the input signal is not stable.

A Q of ten perhaps has the most general application; it is sufficiently high to yield good rejection of unwanted signals, and low enough to assure easy tuning and accurate gain.

In light of the preceding comments regarding Q, select the desired operating Q and tune the instrument as carefully as possible for peak resonant output.

3.5 NOTCH FILTER

Essentially, notch operation is the opposite of resonance or tuned amplifier operation. Instead of trying to amplify only one frequency while rejecting all others, the object is to completely remove one frequency while amplifying all others. Except that one makes use of the Notch Output instead of the Resonance Output, and tunes for minimum output instead of for maximum, notch filter operation is very similar to tuned amplifier operation. Figure III-4 shows the notch response as a function of Q and normalized frequency.

A particularly significant relationship not illustrated in Figure III-4 is that between Q and notch depth, namely that notch depth is completely independent of Q. No greater rejection of an unwanted signal is obtained at high Q's than is obtained at low Q's. And, in fact, practical considerations will usually result in lower rejections at higher Q's. What Q does affect is the width of the stopband (set frequency divided by Q). With high Q, only the set frequency is rejected. With low Q, signals at frequencies close to the set frequency are attenuated as well.

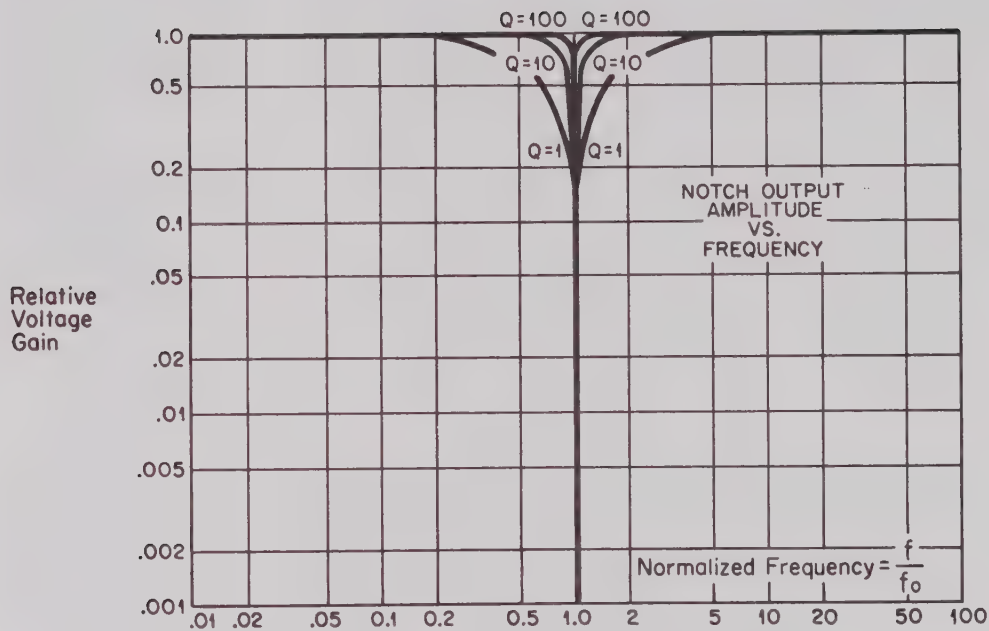


Figure III-4. NOTCH OUTPUT CURVES

In addition to determining the stopband width, Q determines the phase of the Notch Output as indicated in Figure III-5. Although undefined at the resonant frequency (Set Notch Control adjusted for deepest notch), the phase of the Notch Output at frequencies slightly above and below resonance will be plus and minus 90° respectively. At frequencies well below or above resonance, the Notch Output is in phase with the input. The higher the Q , the closer a given frequency component can be to the resonant frequency without undergoing significant phase shift. At a Q of ten, for example, the phase difference between second harmonic signal at the input and at the Notch Output will be less than five degrees. At a Q of 100 this phase difference will be less than one degree. Third and higher harmonics will, of course, be phase shifted even less. As phase distortion is critical in many applications, the small phase error achievable with the Model 110 Notch Output offers considerable advantage over conventional low Q notch filters having high phase distortion such as the twin-tee.

A procedure suitable for notch filter operation follows.

- (1) Select the gain setting appropriate to the signal amplitude. The same restrictions apply here as apply to flat and tuned resonance operation.
- (2) Select a good "working value" of Q . Again a Q of ten will generally prove satisfactory.

- (3) Connect the input signal.
- (4) Tune for minimum notch output.
- (5) Adjust the Set Notch Control for minimum notch output.
- (6) Change the Q setting as necessary to obtain the desired bandwidth.
- (7) Retouch the tuning and Set Notch Adjustment to restore minimum notch output.

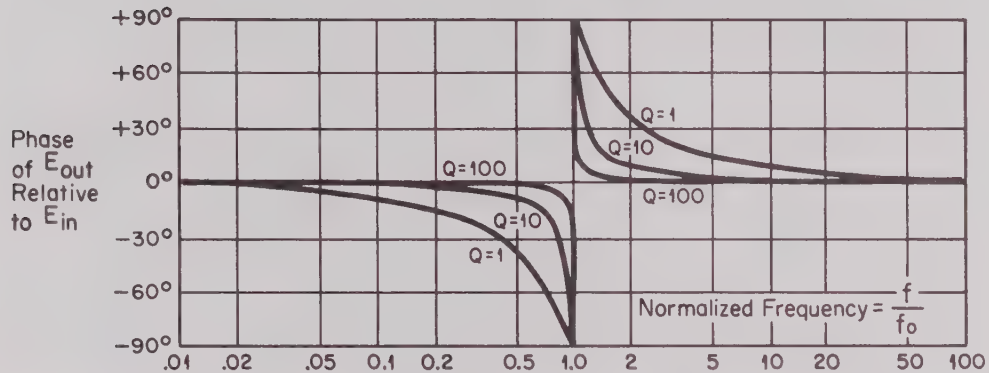


Figure III-5. NOTCH OUTPUT PHASE SHIFT AS A FUNCTION OF NORMALIZED FREQUENCY

Assuming completion of steps "(1)" through "(3)", the next step is to tune the instrument until the set frequency signal at the Notch Output is a minimum. It is important to realize that frequencies far from the tuned frequency, including harmonics of that frequency, will appear at the notch output unattenuated. At the same time, signal at the tuned frequency is available at the Resonance Output, and all components of the input signal are present at the Flat and Allpass Outputs. It is again necessary to monitor the output to achieve accurate tuning. This time, however, the internal voltmeter will generally prove to be of little value because the notch is sufficiently deep to preclude a reasonably up-scale meter indication, even on the most sensitive range. A high sensitivity oscilloscope is the preferred instrument for monitoring the notch output during tuning, although the internal voltmeter could be used (Amplifier Monitor Selector set to "N") where achieving maximum notch depth is not essential. If the input signal or flat output are suitable for triggering the oscilloscope, tuning becomes a bit easier, as the rate of phase shift per unit tuning adjustment is greatest exactly where the notch output is minimized. This changing rate of phase shift frequently serves as a better guide than does the observed amplitude.

After tuning for minimum notch output, the next step is to deepen the observed notch to its greatest possible depth. This is accomplished by adjusting the Set Notch Control. In the preceding discussion of tuned amplifier

operation, it states that once set, the set notch control adjustment generally need not be readjusted. Where one is interested in obtaining the deepest notch, however, this no longer applies, and the Set Notch Control setting will have to be touched up after changes in frequency or Q.

Having achieved the deepest possible notch, increase the Q as necessary to obtain the desired notch bandwidth. Changing Q will probably require a "touch up" of the setting of the tuning vernier and Set Notch Control to retain full notch depth.

One interesting result of having simultaneously available resonance and notch outputs is that a signal comprising two separate frequencies can easily be broken up into its component frequencies. If the composite signal is applied to the input and the Model 110 tuned to one of the two frequencies, the tuned frequency component will appear at the Resonance Output and the other component at the Notch Output.

It may be observed that the tuning setting which yields maximum resonance output differs from that which yields minimum notch output. This difference is a function of Q and frequency. With most combinations of Q and frequency setting, the difference is negligible, but with a combination of low Q and high frequency it is noticeable. The worst case is obtained at a frequency of 110 kHz and a Q of one. Under these conditions the tuning difference may be as great as eight percent. By tuning for maximum notch depth, the resonance output error will be small because of the wide bandwidth at low Q's. At a Q of ten (the "specifications Q"), the tuning difference is reduced to 0.8% at the highest frequencies. Below 10 kHz it is negligible.

3.6 ALLPASS OPERATION

As previously mentioned, the allpass circuitry works on the phase of the applied signal but not on the amplitude. With respect to amplitude, the Allpass Output is like the Flat Output. With respect to phase, frequencies at and near the tuned frequencies will be phase shifted as indicated in Figure III-6. Note that the phase shift at resonance is exactly 180°. At frequencies slightly below resonance the phase shift is less. At frequencies slightly above resonance it is greater. How much less or how much greater depends on the Q as shown in Figure III-6.

As far as gain selection, adjustment of the Set Notch Control, and characteristic time constant are concerned, the same considerations apply as for tuned amplifier operation.

3.7 SMALL SIGNAL AMPLIFICATION

The minimum signal a given amplifier can accept and still give useful output depends on how much noise the amplifier produces. Optimum noise performance is achieved under those conditions where the amplifier adds the least additional noise to that already accompanying the input signal. The minimum noise which can accompany a signal is the thermal noise developed across the

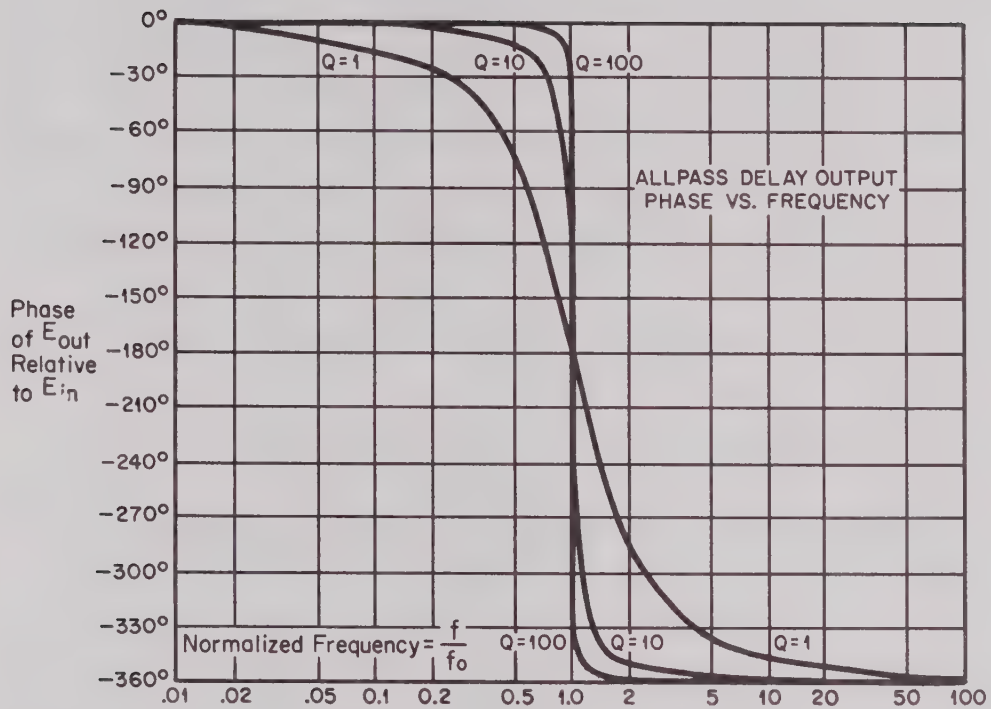


Figure III-6. ALLPASS OUTPUT RESPONSE

source resistance of the signal. Its magnitude is:

$$E = \sqrt{4kTBR}$$

E = volts rms
 k = Boltzmann's constant, 1.38×10^{-23} joules/°K
 T = absolute temperature in degrees K
 B = noise bandwidth in Hz = 3 dB bandwidth $\times \pi/2$
 R = source resistance in ohms

This noise and the noise produced by the amplifier can be related by noise figure, where noise figure is defined as:

$$NF \text{ (dB)} = 20 \log_{10} \frac{\text{Noise Voltage Per Unit Bandwidth at Amplifier Output}}{\text{That Portion of Numerator Attributable to Source Thermal Noise}}$$

By plotting noise figure as a function of frequency and source resistance, noise contours are generated which define the noise performance of an amplifier. Figure III-7 is a plot of the noise contours for a typical Model 110.

The following examples should illustrate the utility of these contours. Suppose one intended to operate at a frequency of 1 kHz with a Q of 10. The noise bandwidth will be $10^3/10 \times \pi/2$ (noise bandwidth = 3 dB bandwidth $\times \pi/2$) or 157 Hz. Further suppose that the source resistance is 100 kilohms. From this information one can readily calculate the source resistance thermal noise. Putting these values into the thermal noise equation, one obtains:

$$E = \sqrt{4 \times 1.38 \times 10^{-23} \times 3 \times 10^2 \times 1.57 \times 10^2 \times 10^5} \text{ or } .51 \times 10^{-6} \text{ volts rms}$$

From Figure III-7, the Model 110 noise figure at 1 kHz with a 100 kilohm source resistance is 0.5 dB. Putting this figure and the thermal noise value into the equation defining noise figure, and then solving for the total noise one obtains:

$$\text{Total Noise} = \text{Thermal Noise} \times 10^{\frac{NF}{20}}$$

or

$$\text{Total Noise} = .51 \times 10^{-6} \times 10^{.025} = .54 \times 10^{-6} \text{ V rms}$$

In other words, the smallest signal one could handle would have to be "large" relative to .54 microvolts rms. By increasing the Q and thereby narrowing the bandwidth the noise performance of the instrument could be further improved. Suppose in the example the Q were increased to 100, reducing the bandwidth from 157 Hz to 15.7 Hz. The source thermal noise over this bandwidth is approximately .16 microvolts instead of the previous .51 microvolts, and the total noise is reduced to .17 microvolts. Where one is concerned with wide band (white) noise, increasing the Q will result in an improvement in voltage signal-to-noise ratio proportional to the square root of the ratio of the new to the original value of Q (the power signal-to-noise ratio improvement is directly proportional to the Q ratio).

One possible confusion which might arise in the use of contours involves amplification of low level signals from low resistance sources. Suppose the source resistance in the example above were 10 ohms instead of 100 kilohms. A glance at Figure III-7 shows that the noise figure is much greater at 10 ohms than at 100 kilohms. It is immediately "obvious" that steps should be taken to operate from the higher source resistance, where the noise performance will be much improved. One easy but completely wrong solution is to insert a 100 kilohm resistor in series with the input. Adding resistance in this manner only adds the 100 kilohm thermal noise to that developed in the ten ohm source. What the noise contour says is that the noise contributed by the amplifier is only slightly larger than that contributed by a 100 kilohm resistor, but much larger than that contributed by a ten ohm resistor. The correct way to take advantage of the contours in this case is to use a 1:100 signal transformer to step up the source resistance "seen" by the amplifier from 10 ohms to 100 kilohms. Such a transformer would increase both the source resistance and the signal amplitude, resulting in an overall improvement in signal-to-noise ratio at the output. If an appropriate signal transformer is not available, work directly from the 10 ohm source.

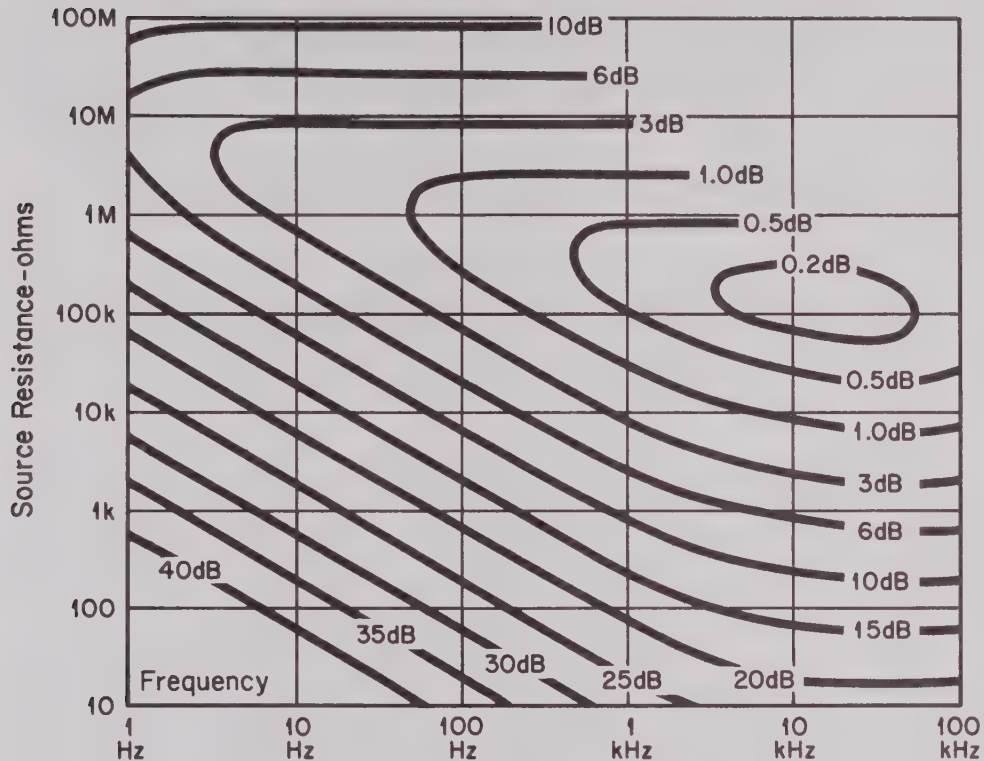


Figure III-7. NOISE CONTOURS FOR A TYPICAL MODEL 110

Needless to say, there are many other types of noise besides thermal noise developed in the source resistance. In a given experiment, any one of these might prove dominant and dictate a higher minimum usable signal level. Calculations based on thermal noise alone show the best theoretically attainable performance, which, although approachable, is difficult to attain in practice.

3.8 DISTORTION ANALYZER OPERATION

Two features of the Model 110, the first being the extremely low distortion which the instrument adds to an input signal, and the second being its capability of removing the fundamental of the signal (rejection greater than 100 dB), make the instrument particularly useful as a high sensitivity distortion analyzer.

Distortion analysis operation is essentially the same as notch filter operation (page III-7). A signal whose distortion is to be measured is applied to the input. Then the instrument is tuned to the input frequency, and the Frequency Vernier and Set Notch Controls are adjusted to completely remove the fundamental from the Notch Output. The notch output signal will then comprise only the harmonics of the input together with any harmonics and noise contributed by the Model 110. By dividing the rms amplitude of the Notch Output by the rms amplitude of the input signal and then multiplying the quotient by 100, one obtains the distortion content of the input signal expressed as percent distortion.

An important requirement to obtaining accurate distortion measurements is that the distortion contributed by the measuring instrument be low. Distortion contributed by the Model 110 is a function of the resonance output amplitude. At full scale output the distortion contributed will be less than 0.1%. By decreasing the gain to obtain slightly less than 1 V rms resonance output (optimum output level for distortion measurements), the distortion contributed by the instrument will decrease to less than .01% allowing the harmonic content of even relatively "pure" sine waves to be measured.

Assuming that the input signal is at least a "reasonable approximation" of a sine wave, the signal level at the Notch Output will be too low to measure with the internal voltmeter. Several alternative measurement methods are suitable. One could use an oscilloscope, a high sensitivity AC voltmeter, or, in those cases where it is important to obtain exact rms values, a true rms voltmeter such as the HP type 3400 A.

Where it is desirable to make distortion measurements of the highest possible sensitivity, or to measure the individual harmonics separately, the Model 110 can be used in conjunction with a second tuned amplifier such as another Model 110 or any PAR Lock-In Amplifier. To make such a measurement, adjust the gain of the Model 110 (that monitoring the signal) for a resonance output amplitude of 100 mV rms. At this level, the total harmonic distortion contributed by the Model 110 will be less than 0.001%. However, at this low level, there is sufficient noise at the Notch Output from both the input signal and from the Model 110 to mask the harmonics and thereby preclude the use of an ordinary rms voltmeter. By using another Model 110 or Lock-In Amplifier, most of the noise can be rejected and distortion levels on the order of 0.001% easily measured. The gain of the second tuned amplifier should be set as high as possible without incurring overload. Tune the second amplifier to each harmonic and measure its amplitude at the resonance output. The total harmonic distortion is easily computed, as it is numerically equal to the square root of the sum of the squares of the individual harmonics. Usually measurement of the second through the fifth harmonics is sufficient in sine-wave analysis, the contribution of higher order harmonics generally being negligible. Accurate measurement of such low distortion levels requires that the frequency of the fundamental be in the range of 100 Hz to 10 kHz.

Two other factors to be considered in doing distortion analysis are frequency range and the choice of Q. With regard to the first, fundamental frequencies over the entire range of the instrument can be nulled. However, as the upper frequency response of the Notch Output is about 330 kHz, one is restricted to third harmonic measurements when the tuned frequency is 110 kHz. With regard to Q, excellent results are generally obtainable at a Q of 5. With this value of Q, the second harmonic will be attenuated less than 1% (higher harmonics will be attenuated even less, of course), and there is no practical advantage in doing distortion analysis with higher Q's.

3.9 WAVE ANALYZER OPERATION

Wave analysis is essentially the same as tuned amplifier operation. An input signal is connected and the instrument is tuned for maximum resonance output. Particular to wave analysis is sequentially tuning to each of the

component frequencies to measure and record them separately. The resulting data, plotted as a function of frequency and amplitude, describe the input signal. Usually the signal to be analyzed is fairly complex and not suitable for straightforward analysis (Fourier series serving better to specify well defined waveforms).

The three dB bandwidth of an analyzer (set frequency divided by Q) is commonly referred to as its resolution and determines how close adjacent frequency components can be without one influencing the indication obtained in measuring the other. Expressed in percent, resolution is given by $100/Q$, and the resolution range of the Model 110 is 1% to 100%, according to the Q setting. Although limited to a 1 kHz bandwidth at its upper frequency limit, the resolving bandwidth in Hz at midrange frequencies is excellent with high Q's and equally good at low frequencies with relatively low Q's.

Where the amplitude of an individual component is high enough, the internal voltmeter will yield good measurements. However, in using the internal voltmeter, bear in mind that it is average responding. With a sinusoidal input to the voltmeter, such as would be obtained with narrow bandwidth and good rejection of adjacent frequency components, the meter will accurately indicate the rms value of the frequency of interest. If the input to the voltmeter is nonsinusoidal, such as when the bandwidth is large relative to the separation between the frequency of interest and adjacent frequencies, the meter indication will be in error. The amount of error depends on a number of factors including the relative phase and amplitude of the various components of the resonance output signal. Although hard to specify in a simple, generally applicable manner, the following error limitations can be stated. Under no circumstances will an average responding meter indicate more than 11% high (worst case - square wave), and, providing the input waveform is other than low duty factor pulses, it is unlikely that the indication will ever be more than 20% low. Noise having a gaussian distribution, for instance, yields an indication about 11½% low, provided no overload occurs on the peaks. Where more accurate indications under the specified conditions are required, measure the resonance output with a true rms meter.

A better way of doing wave analysis is to use two Model 110s and, in effect, do distortion analysis. The signal to be analyzed is supplied to the first unit, and its Notch Output in turn supplied to the second. Any given interfering component can be notched out with the first unit, and the component of interest measured by examining the Resonance Output of the second.

3.10 OSCILLATOR OPERATION

To transfer the Model 110 to the oscillator mode of operation, set the Q Selector Switch to either "OSC." or "SYNC. OSC." (the latter if one intends to synchronize the oscillator with an external signal). Oscillation at the tuned frequency will commence immediately. Those controls which do not directly affect oscillator operation become ineffective. Included are the Gain and Set Notch Controls, along with the two Amplifier Monitor Controls.

The tuning dials control the frequency of oscillation. The dual-concentric Oscillator Amplitude Control determines the amplitude of the signal supplied to the Oscillator Output Jack. The outer selector determines the maximum

available output and full scale meter indication, while the inner is a vernier which allows linear amplitude adjustment from zero to the value indicated by the setting of the Outer Selector.

It is important to realize that the meter does not indicate the open circuit rms value (the case when the internal voltmeter is being used to monitor one of the other outputs), but rather the rms signal level at the output when the output is loaded with 600 ohms. The open circuit output is twice the amplitude indicated by the meter.

When the Q Selector is set to "SYNC. OSC.", an external signal can be connected to the Input Jack to synchronize the oscillator. Although the fundamental of the synchronizing signal need not be at the set frequency, the signal must contain harmonics of sufficient amplitude at the set frequency to synchronize the oscillator at multiples of the applied fundamental. If necessary, the entire instrument gain is available to amplify the synchronizing signal. When operating in the synchronized oscillation mode, particularly when attempting to synchronize from harmonics, one must take care to avoid overloading the input amplifier. The limit for the input signal is the same as for the other modes of operation, that is, the input signal should not exceed $7.5/G$ volts peak, where G is the selected gain.

During oscillator operation, the other four outputs remain active. An approximately 1 V rms signal at the tuned frequency is available at the Resonance, Allpass, and Flat Outputs. The signal at the Notch Output is a highly distorted sine wave approximately 0.1 V rms in amplitude. The amplitude of these signals is independent of the oscillation output level. They could be used to synchronize other equipment or be put to other use. Special application for the Allpass Output is possible because this signal is 180° out-of-phase with the flat and resonance outputs.

SECTION IV THEORY AND CIRCUIT DESCRIPTION

4.1 INTRODUCTION

This section of the manual discusses the organization and functioning of the Model 110 Wave/Distortion Analyzer on both the block diagram and circuit analysis levels. Referring to Figure IV-1, a simplified block diagram of the instrument, note that the instrument essentially comprises a series of interconnected amplifiers. Signal applied to the input is first amplified in the broad-band Preamplifier, which provides all of the instrument gain. From the output of the Preamplifier, the signal is applied to the Selective Amplifier, as well as to the "flat" amplifiers which provide the individual outputs. The gain of the Selective Amplifier is one at the resonant frequency and less than one above and below the resonant frequency, with the attenuation per fractional frequency deviation from resonance being a function of the selected Q. Besides providing the Resonance Output, the Selective Amplifier furnishes signal to the Notch and Allpass Output Amplifiers, where it is combined with the preamplifier output signal in the manner appropriate to generate these outputs. When the instrument is functioning as an oscillator, positive feedback is applied around the Selective Amplifier and the amplifier oscillates. The oscillation amplitude is maintained at a constant level by an AGC (automatic gain control) circuit which monitors the signal level at the output of the Selective Amplifier and controls the amount of positive feedback. An oscillator output power amplifier provides isolation and raises the signal to the required level. A final attenuator, adjustable by means of a front-panel control, determines the signal level at the Oscillator Output Jack. Finally, an AC voltmeter circuit, actually an AC to DC converter, monitors any one of the several outputs and provides a panel meter indication of the signal level at the monitored output. Each of these "blocks" is discussed in greater detail in the following paragraphs.

4.2 PREAMPLIFIER

Referring to the Chassis Wiring Diagram on page VIII-7, note that the Preamplifier actually consists of a series of individual amplifiers, each of which, with the exception of A1, has a gain of ten. Maximum possible gain is realized when all of these amplifiers are cascaded. The front-panel Gain Switch determines the number of amplifiers "in" the circuit at any time. An attenuator between amplifiers A4 and A5 furnishes the 1-2-5 sequence within each decade of gain. The schematics of these amplifiers are on page VIII-2. Observing this schematic, note that, of the five preamplifier stages, four, A2 through A5, are simple gain-of-ten operational amplifiers. The first amplifier, A1, is essentially a source follower with considerable associated circuitry to achieve low distortion. First consider A1.

Input signal is routed through C107 to the gate of source follower Q111, the input impedance of which is established by R124 at 10 M Ω . The remaining transistors "linearize" Q111, that is, give it a low-distortion unity gain. To see why this is so, consider the quiescent conditions. Q107 is a constant current source which establishes the current through Q111 at 3.5 mA. A second constant current source, Q112, supplies the current for Q111 and for the

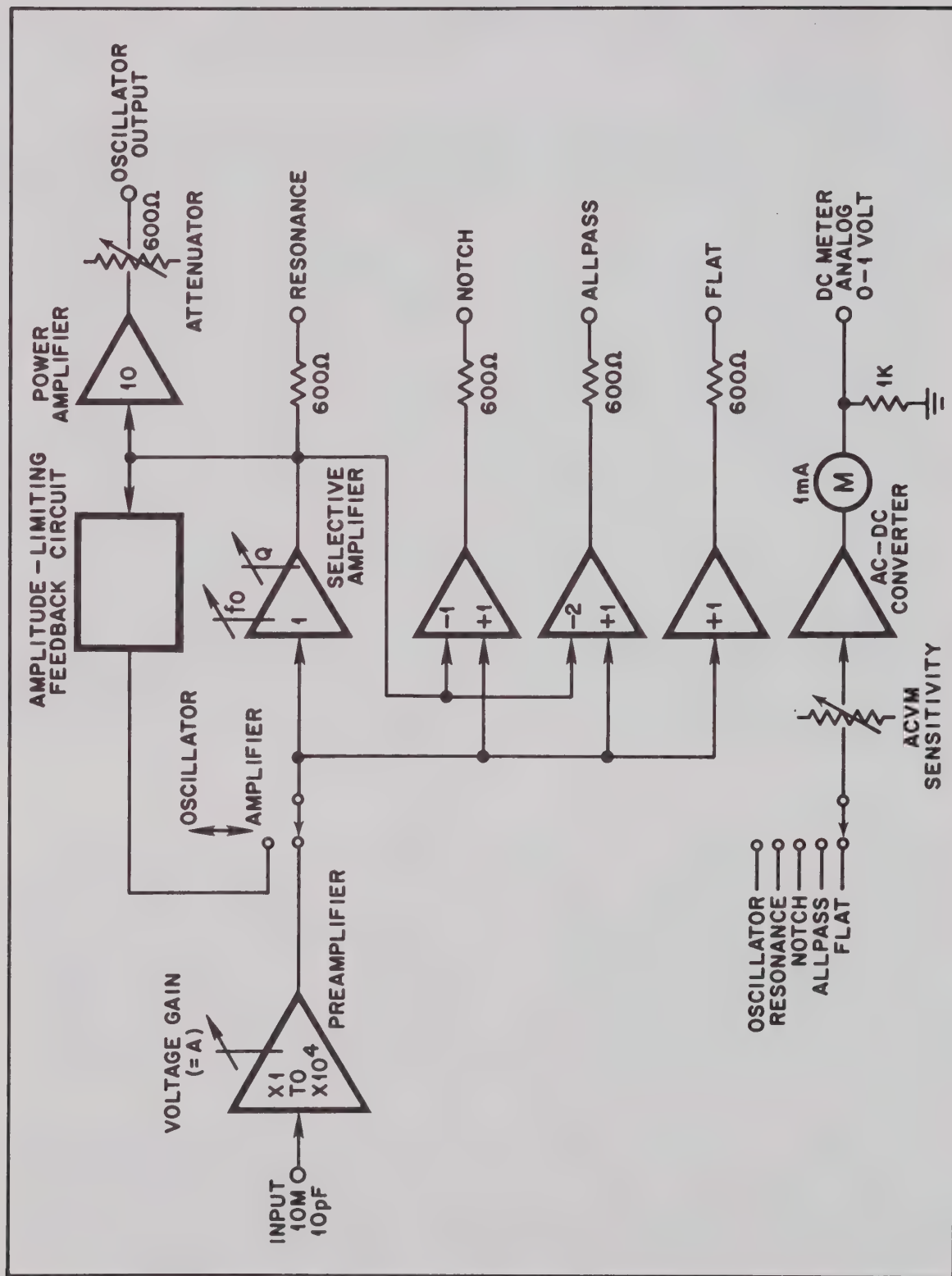


Figure IV-1. SIMPLIFIED BLOCK DIAGRAM OF THE MODEL 110

R125-R119 divider. Emitter follower Q110 maintains the drain potential of Q111 at -0.6 V relative to the potential at the junction of R119 and R125. Dynamically, the source of Q111 exactly follows the gate, as will be shown later. C110 couples this source signal to the base of Q110 and hence to the drain of Q111. In other words, the same signal appears at the gate, source, and drain of Q111. The voltage across the transistor never varies. Pair Q108-Q109 constitute a simple operational amplifier which controls the current supplied by Q112. The current supplied by Q112 is automatically maintained at the level necessary to set the potential at the summing point (base of Q109) at the reference level ($+15$ V at the base of Q108). It is this automatic current control which assures that the signal at the source of Q111 will be an exact replica of the signal at the gate. To show why this is so, assume a positive excursion at the gate of amplitude " e_1 ". In response to this step, a positive excursion of amplitude " e_2 " appears at the source and the current through Q111 increases. This increase incurs a negative excursion at the collector of Q110, unbalancing pair Q108-Q109. Consequently, the current through Q112 is automatically adjusted to restore $+15$ V at the base of Q109. This in turn is achieved only when the current through Q111 is returned to its quiescent state level, that is, when " e_2 " is exactly the same as " e_1 ". To summarize, source follower Q111 always has the same potential across it and the same current through it. This is true under both static and dynamic conditions. As a result, linear, low-distortion operation is assured, and the gain is exactly one.

The next amplifier in the preamplifier chain is A2. Because this circuit is a basic one, which, except for minor variations, appears elsewhere throughout the instrument, it is described in detail here. Transistors Q113 and Q114 constitute the differential amplifier, with the input at the base of Q113 and the summing point at the base of Q114. Emitter follower Q116 provides a low impedance output and Q115 assures that the open-loop gain is very high. Feedback through R137 determines the gain, which approximately equals the ratio of R137 plus R140 to R140, or ten. Trim-potentiometer R142 serves as a fine gain adjustment.

Amplifier A3 is identical to A2, and so requires no separate description. Amplifiers A4 and A5 are also simple operational amplifiers, though of a more "conventional" design; each consists of two cascaded differential pairs, with the output being taken from the collector of the output transistor. Both amplifiers are non-inverting and have a gain of ten. Note that amplifiers A1, A2, and A3 are decoupled from the remainder of the circuitry by separate regulators which develop ± 20 V from the generally distributed ± 24 V.

4.3 INTRODUCTION TO SELECTIVE AMPLIFIER AND OUTPUT AMPLIFIERS

The "heart" of the Model 110 is the Selective Amplifier. To see how this amplifier functions, refer to Figure IV-2, a block diagram of the Tuned Amplifier and its associated output amplifiers. For analysis purposes, the Selective Amplifier is considered to consist of, not only the circuitry shown in the selective amplifier "block", which simply identifies the circuitry shown on the Selective Amplifier Schematic (page VIII-3), but also the Resonance Output Amplifier (schematic of Output Amplifiers is on page VIII-4). Analysis of the circuitry having as its input the Preamplifier output signal (point A, Figure IV-2), and, as its output, the Resonance



Output shows that the amplifier exhibits a bandpass characteristic having a response identical to that of a parallel resonant circuit. Its voltage transmission is analogous to the voltage which would appear across a parallel RLC circuit in response to an input current drive. Hence, if the Q and center frequency are specified, the frequency response can be described by the "Universal Resonance Equation", which follows.

$$\frac{E_{out}}{E_{in}} = \frac{j \frac{f}{Qf_o}}{\left[1 - \left(\frac{f}{f_o} \right)^2 \right] + j \frac{f}{Qf_o}} \quad (1)$$

Furthermore, it can be shown that:

$$f_o = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}, \quad (2)$$

and that:

$$Q = \frac{(G+1) \sqrt{R_1C_1R_2C_2}}{R_1C_1 + R_2C_2}. \quad (3)$$

An examination of these three equations reveals several of the "features" of the Selective Amplifier and hence of the Model 110 as a whole. Among them are:

- (1) Transmission at resonance ($f = f_o$) is exactly unity, even if $R_1C_1 \neq R_2C_2$. This is a particularly desirable feature because it obviates the need for precise tracking between R_1C_1 and R_2C_2 as the instrument is tuned.
- (2) The transmission approaches zero at frequencies very much higher or very much lower than the resonant frequency. Hence the very high "ultimate attenuation" exhibited by the instrument.
- (3) Q is a function of the gain of a single amplifier.
- (4) The gain at resonance is, in principle, independent of Q. However, because components are not ideal, some dependence exists as explained in Section III.
- (5) Q is only very weakly dependent on tracking between R_1C_1 and R_2C_2 for small tracking errors. For example, if $R_1C_1 = 1.1 R_2C_2$, Q will be in error by only about 0.1%. For all practical purposes, equation "(3)" can be considered as simply being $Q = \frac{G+1}{2}$, where G is the gain of the Q Amplifier.

To see how the Selective Amplifier functions, consider the case of an input signal at the tuned frequency. Referring to Figure IV-2, note the several

phasor diagrams, which define the amplitude and phase of the signal at critical points. Assume that a signal at the resonant frequency is available at the output of the Preamplifier. Let this signal be represented by the "unit phasor" [phasor diagram (1)*], a phasor of "unit" amplitude and at zero degrees. This signal is applied at point A to the Selective Amplifier input stage, a gain-of-one, non-inverting amplifier. The output of this amplifier (point B) in turn drives a second non-inverting amplifier whose output is at C. Note that the Q Amplifier also drives point B. However, at resonance, the three inputs to the Q Amplifier exactly cancel, and as far as this "at resonance" discussion is concerned, the Q Amplifier may be regarded as being out of the circuit. Consequently, the signal at C is a replica of the signal at A. Observe that the signal at C is applied to three different places, the input of the phase-shift network, the non-inverting, gain-of-one input of the following amplifier, and the input of the Q Amplifier. The signal at the output of the phase-shift network is applied to the inverting, gain-of-two input of the following amplifier. Observe from phasor diagram (4) that this signal lags the signal at A by 45° and that its amplitude, relative to the signal at A, is $1/\sqrt{2}$. This phase shifted signal is combined with the non-phase shifted signal in the following amplifier to produce a signal at F which leads the signal at A by 90° and which is the same amplitude. In the following second phase-shift network, this signal is lagged 45° by the second phase-shift network to provide a signal at G which leads the signal at A by 45° and which has an amplitude of $1/\sqrt{2}$. Both this signal and that which lags the "A" signal by 45° are routed through isolation, non-inverting, gain-of-one amplifiers. Their outputs (points I and J) are at plus and minus 45° with respect to the A signal, and their amplitude, relative to the A signal is $1/\sqrt{2}$. These signals are applied to the Resonance and Notch Output Amplifiers in the manner appropriate to generate these outputs. Observe that plus and minus forty-five degree signals are also applied to a pair of inverting, gain-of-one amplifiers, and that these in turn drive the input of the Q amplifier, where they are combined with the signal at C, earlier defined as being the same as the signal at A. At resonance, the three signal currents at the input of the Q Amplifier null, effectively isolating the Q Amplifier from the remainder of the Selective Amplifier. Above and below the resonant frequency, the Q Amplifier input signals do not cancel and this amplifier produces an output signal which opposes the signal at B, thereby causing a net reduction in its amplitude. This amplitude reduction is, of course, accompanied by a phase-shift as well. The higher the selected Q, the higher the gain of the Q Amplifier will be and the greater will be the amplitude of the opposing signal per unit percentage frequency deviation from the resonant frequency. As a result, the output amplitude rolls off at the rate indicated for a standard RLC circuit of equivalent Q.

At frequencies far from resonance, the transmission of the Selective Amplifier approaches zero, as can be seen by referring to Figure IV-2. At very high frequencies, capacitors C1 and C2 shunt all of the signal to ground and no signal is available at I and J. At very low frequencies, the effect of the phase-shift networks is negligible and the I and J signals are of equal amplitude but 180° out-of-phase. When added at the input of the Resonance Output Amplifier; they cancel and again there is no net output.

*These numbers identify the phasors in Figure IV-2 only. They are not the same as the schematic phasors (page VIII-3).

RESONANCE OUTPUT

The Resonance Output is generated by appropriately adding the I and J signals. Continuing to refer to Figure IV-2, observe that these signals are applied to resistors R5 and R6 (a table to the right of the diagram equates these resistor numbers to their schematic equivalents on page VIII-4). From superposition, it is apparent that the signal at the junction of these resistors is in phase with the A signal, and that it has an amplitude of $\frac{1}{2}$ the A signal (phasor diagram 9). This signal is applied to the non-inverting input of the Resonance Output Amplifier, an operational amplifier with a gain of two (ratio of R3 plus R4 to R4). The signal at the Resonance Output Jack then, assuming an input signal at the tuned frequency, is a signal in-phase with the preamplifier output signal and the same amplitude as the preamplifier output signal. Output components not at the resonant frequency appear at the Resonance Output phase-shifted and attenuated to the degree appropriate to the selected Q.

NOTCH OUTPUT

The Notch Output is generated by subtracting the Selective Amplifier output signal from the Preamplifier output signal. Input signal components at the resonant frequency will therefore make no contribution to the Notch Output. Components not at the resonant frequency do of course appear at the Notch Output as discussed in Section III.

Referring to Figure IV-2, observe that the I and J signals are added at the junction of R9 and R10 and applied to the inverting input of the Notch Output Amplifier. Simultaneously, the preamplifier output signal is applied to the non-inverting input of the amplifier, with attenuator R11-R12 providing a factor of three attenuation. Clearly, to obtain zero output at resonance, the net contribution of the resonance and preamplifier signals to the Notch Output must be the same in terms of amplitude. The A (preamplifier output) signal has an amplitude of one. R11 and R12 divide the A signal by three and the gain of the Notch Output Amplifier relative to the non-inverting input is three (ratio of R8 plus the parallel combination of R9 and R10 to the parallel combination of R9 and R10). Consequently, the A signal component at the Notch Output has an amplitude of one and, for components at the resonant frequency, is in phase with the A signal. The gain of the amplifier relative to the inverting input, however, is not three but two (ratio of R8 to the parallel combination of R9 and R10). From Thevenin's theorem, R9 and R10 can be represented by a single 2.5 k resistor, one end of which goes to the summing point and the other end of which is driven by the combined I and J signals, that is, by a signal in phase with the A signal but with an amplitude of $\frac{1}{2}$ the A signal. The component of the Notch Output signal contributed by this signal will be the same amplitude as the A signal component but 180° out-of-phase. These two components cancel to yield zero notch output at the resonant frequency. The equation for the notch output indicated in Figure IV-2 is obtained by subtracting the resonance equation from "A", where A represents the preamplifier output signal. It might be mentioned that, if an oscilloscope were used to monitor the signal at the summing point of the Notch Output Amplifier, the observed signal would be the same as that at the junction of R11 and R12, regardless of the I and J signals. As in any operational amplifier, the summing point level is identically the reference ("normally" ground).

FLAT OUTPUT

The Flat Output is produced directly from the preamplifier output Signal by routing the Preamplifier Output Signal through an operational amplifier connected as a unity follower as shown in Figure IV-2.

ALLPASS OUTPUT

The Allpass Delay Output is synthesized by subtracting twice the resonance output from the preamplifier output signal. As explained in Section III, this output exhibits a flat amplitude versus frequency characteristic and a phase lag which increases monotonically with frequency. At frequencies far lower than the resonant frequency, the phase lag is near zero. At the resonant frequency, the phase lag is 180° , while at frequencies far above the resonant frequency, the phase lag approaches 360° . The "steepness" of the phase transition near the resonant frequency is determined by Q, with the sharper transitions associated with the high Q values.

Referring to Figure IV-2, note that the Resonance Output signal is applied to the inverting input of the Allpass Output Amplifier. The gain relative to the inverting input of the amplifier is two, as given by the ratio of R14 to R15. Consequently, the resonance signal contribution to the Allpass Output is a signal twice the amplitude of the Resonance Output Signal and 180° out-of-phase with it. Simultaneously, the Flat Output Signal, a replica of the signal at the output of the Preamplifier, is applied to the non-inverting input of the Allpass Output Amplifier. The gain relative to this input is three, as given by the ratio of R14 plus R15 to R15. However, because the Flat Output Signal is first attenuated by a factor of three by R16 and R17, the net flat signal contribution to the Allpass Output is a signal of unit amplitude, that is, one half the amplitude of the resonance contribution. The requirements for synthesizing the Allpass Delay Signal are realized, and the resulting output exhibits the allpass characteristic. The allpass characteristic formula shown in Figure IV-2 is derived by multiplying the resonance formula by two and then subtracting the result from "A", the preamplifier output signal.

It should be clear that the signal at the summing point of the Allpass Output Amplifier is simply one third the Preamplifier Output Signal, regardless of the resonance signal. As in the case of the Notch Output Amplifier, the summing point follows the reference or non-inverting input.

4.4 SELECTIVE AMPLIFIER CIRCUITRY

Observing the schematic on page VIII-3, observe that the Preamplifier Output Signal is applied to the Selective Amplifier at the base of Q202. Assuming a resonant frequency input signal, the signal at the base of Q202 can be represented by a "unit" phasor, indicating the signal is of unit amplitude and that it is in phase with the input signal. For purposes of this circuit analysis, which assumes operation with a resonant frequency signal, all signals throughout the amplifier can be defined in terms of this unit phasor.

Q202 is the input stage of the first operational amplifier, which comprises transistors Q201 through Q204. Because this amplifier, and several of the

other circuits shown on the Selective Amplifier Schematic, are nearly identical to the already discussed preamplifier circuits, no detailed analysis is given. The 100% feedback from the emitter of Q204 to the base of Q203 assures that the amplifier functions as a unity follower. Hence, the signal represented by phasor diagram (2) is the same as the Preamplifier Output Signal, phasor diagram (1)*. This signal is applied to the input of a second, similar operational amplifier (Q211 through Q214), which drives the first phase-shift network.

The Q Amplifier (Q207, Q209, and Q210), as explained in paragraph 4.3, is effectively out of the circuit for signals at the resonant frequency. For this reason, it will be considered later. Also, emitter followers Q205 and Q206, which function as a simple "regulator" to provide +9 V at a low impedance, require no detailed analysis.

As mentioned previously, the first phase-shift network provides a phase lag of 45° at the resonant frequency and a net reduction in signal amplitude from "1" to $1/\sqrt{2}$ ". Both this signal and the unshifted signal at the emitter of Q214 are applied to the following circuit, which comprises transistors Q215 through Q217. For purposes of this discussion, these three transistors may be replaced with a single transistor, as shown in Figure IV-3. The simplest approach to understanding the circuit is that of superposition, that is, of considering the effect of each of the input signals separately. Observing Figure IV-3, note that the unit phasor input signal is represented by e_2 , and that the phase-shifted signal is represented by e_1 . First assume that e_1 is zero. The stage then is a common-base amplifier, the gain of which is given by the ratio of R245 to R240, or one. The output produced by e_2 then is just the unit phasor (phasor "a" in the diagram). Now assume e_2 to be zero. The "composite" transistor now acts as an inverting common-emitter amplifier with a gain of minus two (ratio of R245 to the parallel combination of R240, R246, and a number of considerably higher impedance parallel paths). The output produced by e_1 then can be represented by a phasor ("b" in the diagram) which leads the unit phasor by 135° and which has an amplitude of $2/\sqrt{2}$. The resultant of the two outputs is a signal which leads the unit phasor by 90° and which is of unit amplitude. This resultant signal is represented by phasor "c" in the Figure IV-3 diagram. It is also indicated on the schematic at the input of the following operational amplifier (base of Q220).

Consider the signal at the emitter of Q215. Because of the low output impedance of this transistor, the unit phasor signal applied through R240 will have negligible effect on signal at the emitter of Q215, and the signal applied to Q218 will be a replica of the signal at the output of the first phase-shift network. This signal is available at a low impedance at the emitter of Q218, from where it is routed to the Resonance and Notch Output Amplifiers. Observe that the signal is also applied to inverter Q219, the output current of which constitutes one of the three input signals to the Q Amplifier.

Returning to the signal-flow path under consideration, note that the 90°

*These numbers identify the phasors shown on the schematic on page VIII-3 only. They do not refer to the phasors in Figure IV-2.

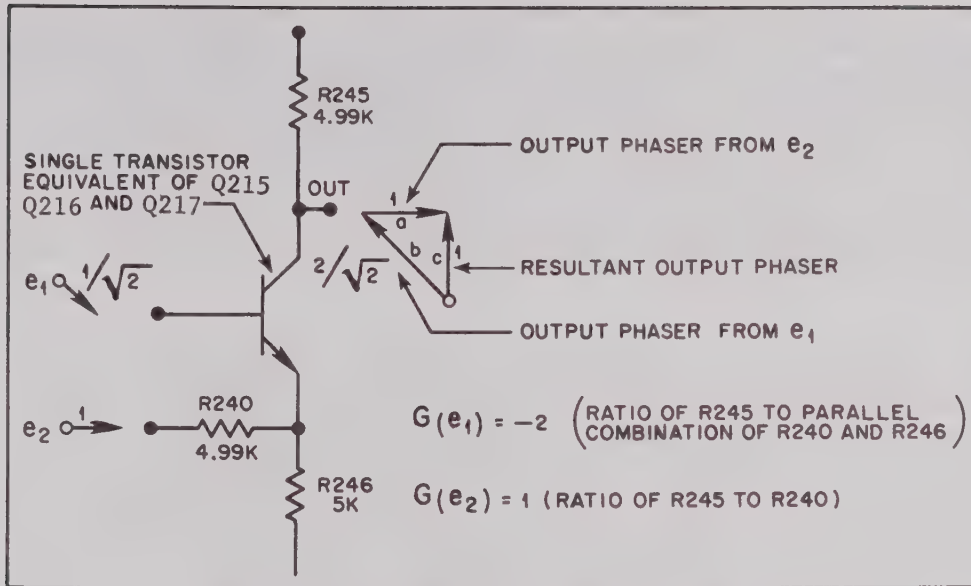


Figure IV-3. SIMPLIFIED VIEW OF PORTION OF SELECTIVE AMPLIFIER SCHEMATIC

signal at the collector of Q217 is applied to another gain-of-one, non-inverting operation amplifier (Q220 through Q223), which drives the second phase-shift network. Again a phase lag of 45° and an amplitude reduction occur; the signal at the output of the network, phasor diagram (13), leads the unit phasor signal by 45° and has an amplitude of $1/\sqrt{2}$. This signal is applied to the following "complementary Darlington" stage (Q224 and Q225), which has two outputs. The inverted output is taken from the emitter of Q225 and constitutes the second input signal to the Q Amplifier. Note that this signal current, which is at 225° due to the inversion, is directly combined with the 135° (-45° inverted) signal current at the collector of Q219, and that the common line is routed to the input of the Q Amplifier at the emitter of Q210. The non-inverted output of the Q224-Q225 pair is applied to emitter follower Q226, which supplies the $+45^\circ$ signal to the Resonance and Notch Output Amplifiers.

Recall that it is essential to the operation of the Selective Amplifier that all three of the input signals to the Q Amplifier exactly null at resonance. Referring to the schematic, note that the plus and minus 45° outputs are inverted, combined, and applied to the emitter of common-base amplifier Q210, the input stage of the Q Amplifier. Simultaneously, the unit phasor signal at the emitter of Q214 is also applied to the emitter of Q210. This signal current and that supplied by the two 45° outputs are developed across the net collector impedance of Q210. The resistors which determine the amplitude of the individual signal currents are R253, R268, and the parallel combination of resistors between the emitters of Q214 and Q210. Note that the front panel Set Notch Control simply allows the net resistance between Q214 and Q210 to be properly set.

At frequencies removed from the resonant frequency, the three signal currents do not null, with a resulting Q Amplifier input signal. This signal is amplified and appears across the Q Amplifier load resistor, R213. Because this signal opposes the unit phasor signal (the degree of opposition being a function of the Q and percentage deviation of the frequency of the applied signal from the tuned or set frequency), the signal applied to Q212, and hence all following circuits, will be reduced in amplitude and shifted in phase. The result is a frequency versus amplitude characteristic (Selective Amplifier and Resonance Output Amplifier) identical to that of an RLC parallel tuned circuit with the same Q.

In addition to common base stage Q210, the Q Amplifier consists of emitter follower Q209 and common emitter amplifier Q207. Constant current source Q208 plays no active role, but simply serves to establish the proper DC levels. The overall gain of the Q Amplifier, and hence the Q, is controlled by changing the gain of both the common base and common emitter circuits. The gain of Q210 equals the ratio of the net collector load impedance, which changes with changes in the Q setting, to 5 kilohms (source impedance of each of the three input currents). The gain of Q207 equals the ratio of R213, the collector load resistor, to the net emitter resistance, largely determined by the resistance between the emitter of Q207 and that of Q206. Changes in the setting of the front-panel Q Control change the gain of the Q Amplifier as necessary to obtain the desired Q. An RC network comprising R214 and C218 tailors the frequency response of the Q Amplifier at the higher Q's.

4.5 OSCILLATE, SYNC. OSCILLATE, AND SET NOTCH

At a final note regarding the functioning of the Selective Amplifier, some explanation of the difference between these three "modes" of operation is warranted. When the front-panel Q Selector Switch is set to "OSC", the Pre-amplifier is disconnected from the Selective Amplifier and positive feedback from the Resonance Output is routed to the input of the Selective Amplifier by way of the Automatic Gain Control Circuit. As a result of this positive feedback, the Selective Amplifier oscillates at the tuned frequency. Note from the Selective Amplifier Schematic that the Set Notch Control is effectively out of the circuit during oscillator operation, the internal feedback from the emitter of Q214 to the input of the Q Amplifier being fixed at the proper level. The Automatic Gain Control Circuit, which is explained in detail further on, samples the output signal and automatically maintains the proper amount of positive feedback.

Synchronized oscillation differs only in that the Preamplifier remains connected to the Selective Amplifier. When the frequency of the signal at the Preamplifier Output is sufficiently close to the "natural" oscillation frequency, the selective amplifier "locks" to the Preamplifier Output Signal.

Finally, when the Q Selector Switch is set to "SET NOTCH", the Selective Amplifier remains connected as an oscillator. However, in this oscillation "mode", the Set Notch Control remains in the circuit and the AGC Circuit is bypassed (the Resonance Output is directly connected to the input of the Selective Amplifier). The Set Notch Control functions as a fine gain control, allowing the gain to be varied over a small range about one. If the Selective Amplifier is oscillating and the Set Notch Control is properly set, the

oscillation amplitude will remain constant. If the gain is slightly high or slightly low, the oscillation amplitude will increase or decrease as appropriate. If the oscillation amplitude is in the range observable on the panel meter (100 mV full scale), the meter can be used to determine whether the oscillation signal is increasing or decreasing, and hence, whether the Set Notch Control is properly set. Clearly, even with the Set Notch Control properly set, the oscillation level, though unchanging, may be too high or too low to be read with the meter. Hence the necessity for adjusting the Set Notch Control to obtain an on-scale indication prior to setting it to its final level.

4.6 OUTPUT AMPLIFIER AND AGC CIRCUITRY

Referring to the schematic on page VIII-4, note that the four output amplifiers are quite similar to the earlier discussed preamplifier stages, and so require no detailed analysis. The principle problem in each case is to establish the correspondence between the components shown in Figure IV-2 and the "real" components shown on the schematic. A table to the right of Figure IV-2 serves this purpose. By cross-referencing between Figure IV-2 and the schematic, one should have little difficulty in identifying the feedback networks, attenuators, and signals.

Continuing to refer to the schematic on page VIII-4, note the AGC circuit, which regulates the amount of positive feedback when the Model 110 is operating as an oscillator. Note that the Resonance Output is applied to the drain of field-effect transistor Q305. The amplitude of the signal at the source depends on the bias of this transistor, which varies directly with the amplitude of the signal at the Flat Output (during oscillator operation the same as the resonance output). Because the source signal is fed back to the input of the Selective Amplifier to sustain oscillation, the automatic bias control maintains the oscillation at the proper level.

The Flat Output Signal is applied through C310 to the base of quiescently cut-off transistor Q307. Associated transistor Q306 establishes the reference for Q307. Quiescently Q306 conducts and Q307 is cut-off. During oscillation, however, Q307 conducts on the negative peaks of the applied signal. The resulting positive pulses developed across R330 forward bias D303 and charge the capacitance between the gate of Q305 and junction of R318 and R319 to establish the bias at the proper level. If the Flat Output amplitude should increase, the bias on Q305 will increase as well, and the AGC Out Signal will be reduced to the level required to restore the proper oscillation level. Similarly, if the amplitude of the Flat Output Signal should decrease, the bias on Q305 will decrease as well, and the resulting increased positive feedback to the Selective Amplifier will restore the oscillation amplitude to the proper level as established by R325, a trim-potentiometer in the bias circuit of Q307.

Note that changes in the setting of the Frequency Range Switch cause different capacitors to be switched into the Q305 bias-filtering circuit, thereby maintaining a reasonable frequency/time-constant relationship over the entire frequency range of the instrument.

4.7 OSCILLATOR POWER AMPLIFIER

Referring to the schematic on page VIII-5, observe that the Oscillator Power Amplifier is a straightforward, non-inverting, gain-of-ten operational amplifier. The front-panel Oscillator Amplitude Control, shown on the schematic at the input of the Power Amplifier, is interposed between the power amplifier input and the output of the Resonance Output Amplifier. There are two power amplifier outputs, a high-level 600 ohm output and a low-level 200 ohm output. The former is routed to the Oscillator Output Step Attenuator, and from there to the Oscillator Output Jack (in the "5 V" position of the Step Attenuator, there is no post-amplifier attenuation). The low-level output is routed to the metering circuit. Recall that the circuit values are selected such that the meter indicates the oscillator output when loaded with 600 ohms, the open circuit output level being twice the level indicated by the meter.

4.8 AC-DC CONVERTER

The AC-DC Converter, which drives the panel meter, is also schematically shown on page VIII-5. DC analysis shows that the portion of the circuit comprising Q401 through Q405 is essentially a non-inverting operational amplifier with a gain of approximately one. Transistors Q401 and Q402 constitute the input pair. The input is applied to the gate of Q401, while the gate of Q402 is the summing point. Differential pair Q403-Q404 provides additional open-loop gain and emitter follower Q405 provides a low impedance drive to the following circuitry. Negative feedback applied through R412 assures stable DC performance. Assuming no input signal, the 0.6 V drop across D404 will be insufficient to bias D405 or D406 into conduction. Consequently, the following circuitry is essentially "disconnected" from the operational amplifier.

Now assume a sine-wave input is applied and analyze the circuit over one cycle of the input signal, beginning with the positive going portion of the input sine wave. The AC gain of the circuit for small signals is essentially the open loop gain of the amplifier. Consequently, a fast positive-going transient appears at the emitter of Q405 as the input sine wave begins to go positive. This transient rises rapidly until D405 becomes forward biased. When this happens, a low impedance path (D405, C410, and C406) is established between the output of the operational amplifier (emitter of Q405) and its summing point, and the amplifier gain is suddenly reduced to approximately one. In response, the transient at the emitter of Q405 gives way to a positive sine curve which follows the positive half-cycle of the input signal. As the input sine wave starts down, D405 eventually becomes reverse biased. At that time, the open loop gain of the amplifier again applies and the sine-wave curve at the emitter of Q405 gives way to a fast negative-going transient, which continues on down until D406 becomes forward biased to re-establish the low gain connection by way of D406, C412, and C406. Again the transient at the emitter of Q405 gives way to a sine curve. When the input signal starts positive, the output follows to the point where D406 cuts off, restoring open loop gain conditions. The resulting positive-going transient at the emitter of Q405 marks the completion of one complete cycle.

From this description it is clear that for a sine wave input of sufficient amplitude, the signal at the emitter of Q405 will consist of a series of square waves, each with a sine-wave "top" and "bottom". Because low gain conditions apply over almost the entire duration of each cycle of the input signal, an oscilloscope examination of the signal at the gate of Q402 would show a sine wave identical to the input signal. The transients occur over such a small fraction of the sine-wave duration that their effect on the observed signal is negligible.

Note the number of "networks" associated with the feedback loop. Each has a different function as follows. Resistor R415, shunted by R417 in series with R418, establishes the gain when either one of the low-gain loops is closed. Trim-potentiometer R418 serves as a gain adjustment. When properly calibrated, a 100 mV rms sine wave input yields full scale meter deflection at the output. Diodes D402 and D403, together with resistor R414, form a fast time constant (0.1 second) shunt for the DC loop (time constant 100 seconds) when large overload transients are applied. By momentarily shorting out R412 if an overload condition exists, the recovery time of the circuit is considerably improved. Normal Q405 emitter current levels are far below the level required to forward bias D402 or D403. The remaining network, consisting of R413 and C408, damps any ringing which might be set up in the DC loop by turn-on or overload transients.

Consider the functioning of the remainder of the circuit. Whenever D405 conducts, C410 is charged positively, and, whenever D406 conducts, C412 is charged negatively. Over a number of cycles of the input waveform, a difference in potential builds up across C410 and C412 and Q406 and Q407 are biased into conduction. As this voltage continues to build, a level is reached where the average charging current balances the average load current through Q406 and Q407, and the C410-C412 potential is proportional to the average of the input signal. A proportional current flows through Q407 and hence through the meter, giving an average responding meter indication of the input signal. The meter scale is calibrated in rms with the appropriate correction employed to give an accurate rms indication with a sine-wave input.

4.9 POWER SUPPLIES

The AC and Unregulated DC Supplies are illustrated on the Chassis Wiring Diagram, page VIII-7. Referring to this diagram, note that either 115 V or 230 V, 50-60 Hz, is routed through the line fuse, Power Switch, and Line Voltage Selector switch to the split primary windings of the power transformer. For 115 V operation, the two primary windings are in parallel. For 230 V operation, they are in series. The secondary output is applied across a rectifier bridge to obtain unregulated plus and minus thirty-five volts. This unregulated DC is supplied to the regulators shown on the Power Supply Schematic, page VIII-6. There are two regulators. The first receives -32 V from the rectifiers and regulates it to -24 V. Zener diode D505 establishes the reference and trim-potentiometer R510 allows the output level to be accurately set. The second regulator takes the +32 V output of the rectifiers and regulates it to +24 V. Note that the reference for this regulator is the -24 V regulated output of the first circuit, and that the output level of the +24 V regulator is determined by the setting of R533.

Three fuses protect the power supply circuitry. Two of these, F2 and F3, are 3/8 ampere, fast-blo fuses in the plus and minus unregulated thirty-two volt lines. The third, F1, is a 4/10 ampere, slo-blo fuse in the AC line before the Power Switch.

SECTION V ALIGNMENT PROCEDURE

5.1 INTRODUCTION

The Model 110 is a reliable instrument, and as such, will give long trouble-free service. However, as an assurance that no component aging effects are taking place which might gradually degrade the performance of the instrument, the following alignment procedure should be carried out yearly.

Because some of the adjustments interact, the entire alignment should be performed in sequence. Any decision to make only a partial alignment should be reserved to someone having sufficient knowledge of the instrument to determine where interaction is a problem and where it is not. The location of the various adjustments and test points is indicated in Figure V-2 on page V-4. Note that each adjustment is identified with a letter for quick identification.

If any problems are encountered in performing the alignment, the operator is referred to the following section on troubleshooting. If assistance or advice is required, contact the factory or one of its authorized representatives, a list of whom appears at the end of the manual.

5.2 EQUIPMENT NEEDED

- (1) Oscilloscope, DC to 1 MHz, 1 mV/cm sensitivity, differential input with a common-mode rejection ratio of 1000:1 or better.

Suggested Instrument: TEKTRONIX type 502A or equivalent.

- (2) DC Voltmeter, input impedance one megohm or higher, 0.5% accurate at 1 V and 24 V.

Suggested Instrument: NLS type X2.

- (3) AC Voltmeter, capable of measuring 250 μ V at 10 Hz and at 1 kHz.

Suggested Instrument: HP type 400EL or equivalent.

- (4) Frequency/Period Counter covering a range of 1 Hz to 110 kHz.

Suggested Instrument: HP type 5512A.

- (5) Signal Generator, sine wave, 1 Hz to 100 kHz.

Suggested Instrument: HP type 202C.

- (6) AC Signal Standard capable of producing a 1 V rms sine wave at 400 Hz with an amplitude accuracy of $\pm 1\%$. Alternatively, an AC Voltmeter accurate to $\pm 1\%$ to aid in adjusting the amplitude of a signal generator to the required amplitude.

Suggested Instruments: KROHN-HITE type 4020 Signal Generator or HP type 400F AC Voltmeter.

(7) Ohmmeter, 5% accurate at 4.75 k.

Suggested Instrument: HP 410C.

(8) Set of Attenuators, 0.2% accurate with a 600 ohm source and a 10 megohm load. Suitable attenuators are shown in Figure V-1 below. Metal film resistors with an accuracy of 0.1% are recommended.

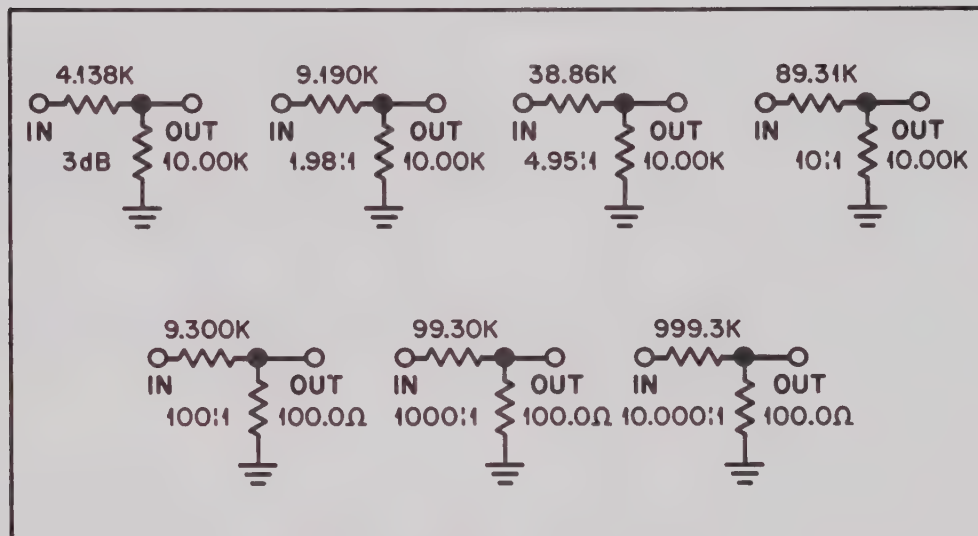


Figure V-1. ATTENUATOR SUITABLE FOR
ALIGNMENT PURPOSES

(9) Resistor, 600 ohms, $\pm 10\%$ (a standard 5% carbon composition 620 ohm resistor will be satisfactory).

(10) BNC "T".

(11) Miscellaneous shielded cables suitable for interconnecting the Model 110 and the test equipment.

(12) Alignment Screwdriver. NOTE: Use of an ordinary screwdriver unduly increases the likelihood of applying excessive torque to the miniature potentiometers.

5.3 PRELIMINARY STEPS

(1) Remove the top and bottom covers.

(2) Rest the unit on its side to gain access to the component side of the printed circuit board.

(3) Plug in the line cord and turn the instrument on.

(4) Set the front-panel controls as follows:

Gain -----	1
Gain Variable -----	CAL.
Frequency -----	4.00, X100
Frequency Vernier -----	0
Q Selector -----	10
Amplifier Monitor Select -----	F
Amplifier Monitor Full Scale -----	1 V
Oscillator Range -----	5 V
Oscillator Amplitude -----	Maximum Clockwise

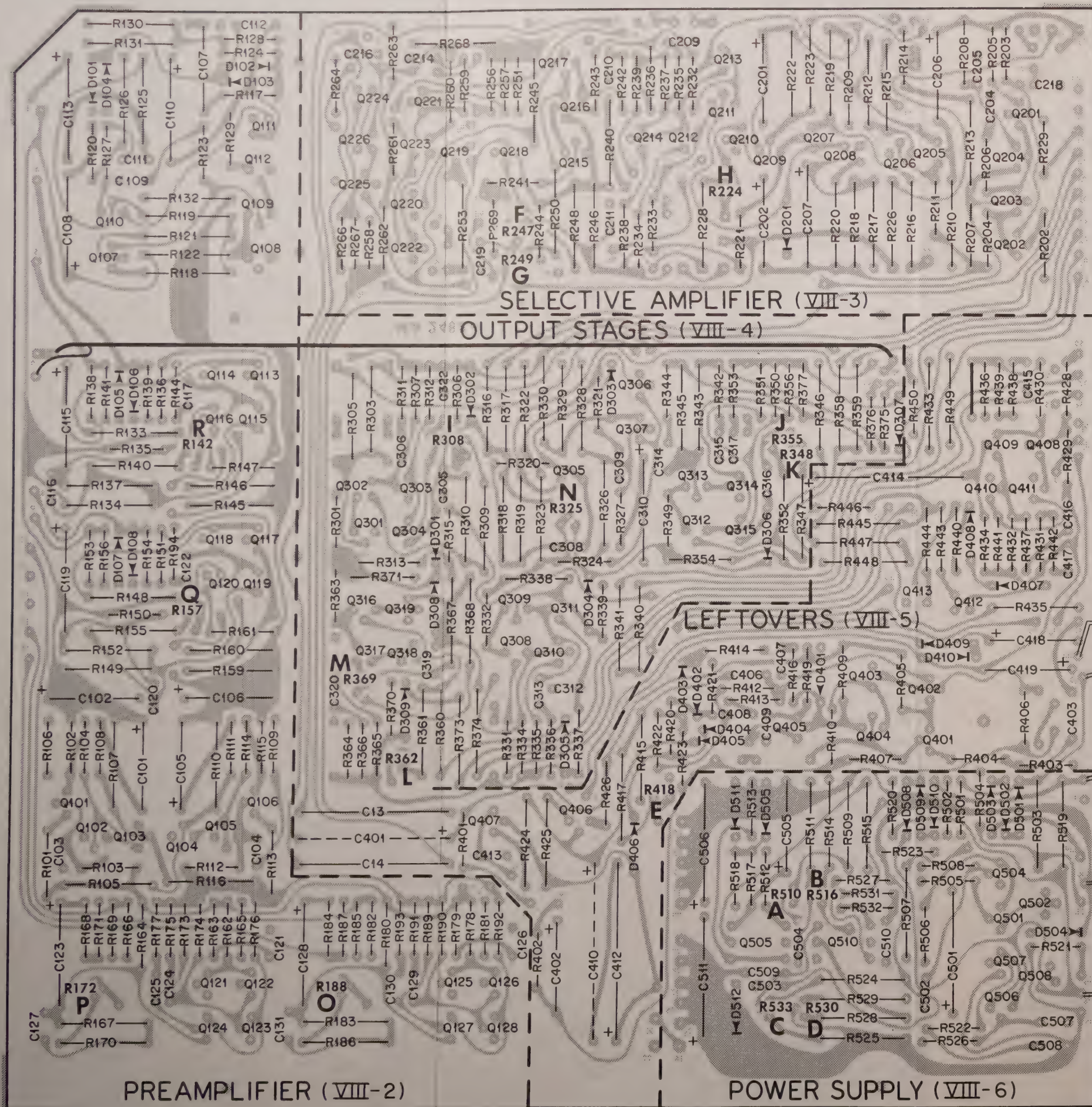
5.4 POWER SUPPLIES

- (1) Connect the DC voltmeter to pin 3 of the rear connector, J100.
- (2) Set Adjustment "A" (-24 V Adjust) for a meter indication of -24.0 V.
- (3) Short the bases of Q505 together (see Figure V-2).
- (4) Set Adjustment "B" (-24 V Balance) until the meter indicates -24 V.
- (5) Remove the short and check that the voltage is still -24.0 V.
- (6) Connect the voltmeter to pin 2.
- (7) Set adjustment "C" (+24 V Adjust) for a meter reading of +24.0 V.
- (8) Short the bases of Q510.
- (9) Set adjustment "D" (+24 V Balance) to where a slight change in the adjustment causes the reading to change sharply from +3 to +32 V or vice versa.
- (10) Remove the short and check that the voltage is still +24.0 V.
- (11) Disconnect the voltmeter.

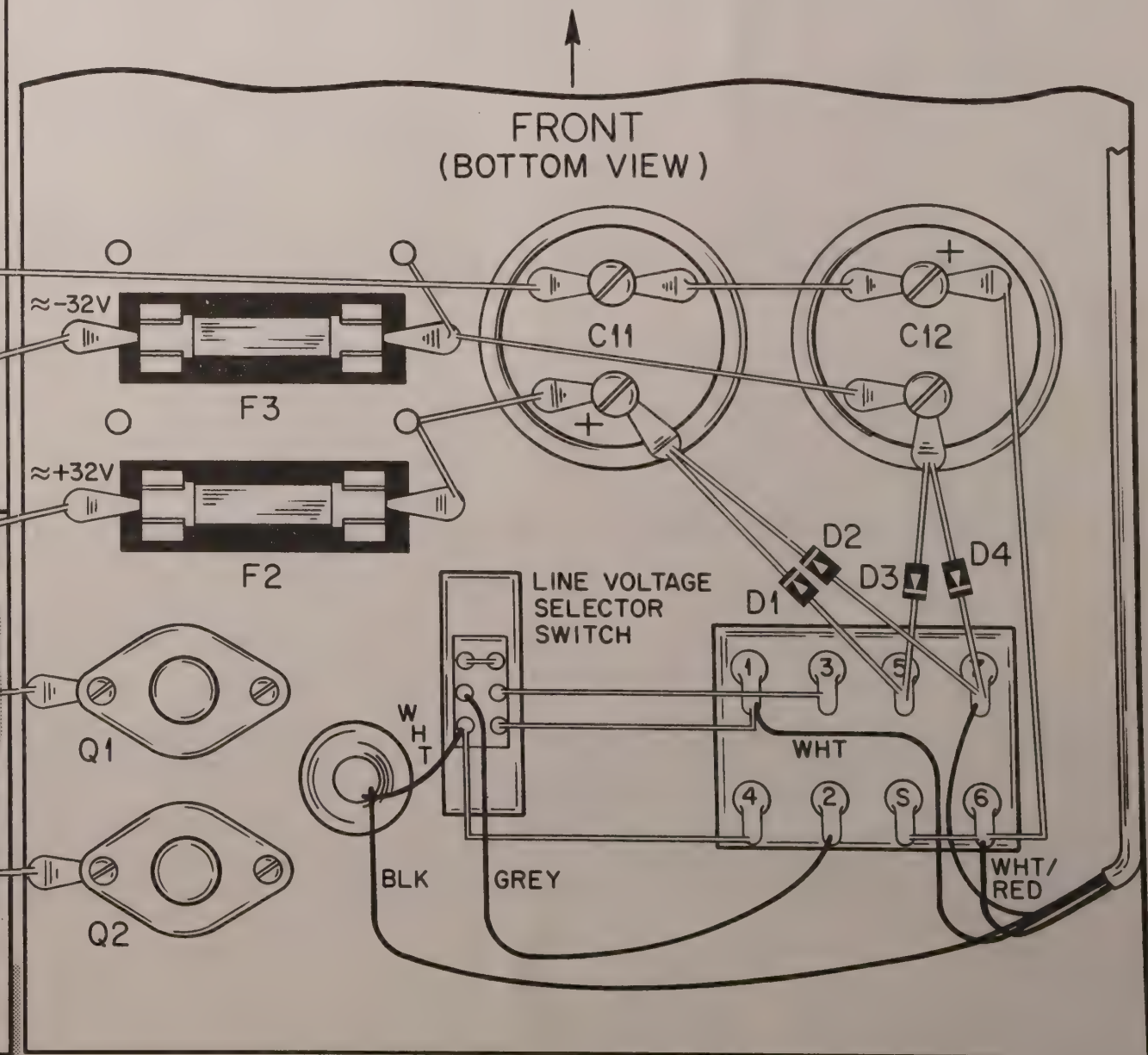
5.5 INPUT AMPLIFIER AND FLAT OUTPUT CHECKS

- (1) Use the DC voltmeter to check for +20 V at the positive end of C102.
- (2) Check for -20 V at the negative end of C106.
- (3) Attach the BNC "T" to the Model 110 Input Jack. Feed the signal generator output (2.8 V ptp at 400 Hz) into the T.
- (4) Connect the oscilloscope differentially between the Model 110 Input Jack (at the T) and the Flat Output. The observed signal should be less than 10 mV peak-to-peak.

Because the gain of the Model 110 is one, the flat output signal should be the same as the input signal. The oscilloscope, connected



ADJUSTMENTS		
Letter	Name	Component
A	-24 V ADJUST	R510
B	-24 V BALANCE	R516
C	+24 V ADJUST	R533
D	+24 V BALANCE	R530
E	METER CALIBRATE	R418
F	LOW FREQUENCY BALANCE	R247
G	OUTPUT ZERO	R249
H	COARSE NOTCH	R224
I	RESONANCE GAIN	R308
J	NOTCH GAIN	R355
K	NOTCH NULL	R348
L	0° GAIN	R362
M	180° GAIN	R369
N	OSCILLATION LEVEL	R325
O	X10 GAIN	R188
P	X100 GAIN	R172
Q	X1000 GAIN	R157
R	X10,000 GAIN	R142



differently, subtracts one signal from the other and displays the difference. An observed signal level of less than 10 mV peak-to-peak indicates that the gain is within 0.36% of one.

- (5) Disconnect the oscilloscope, the signal generator, and the BNC "T".

5.6 METER CALIBRATION

NOTE: THE INSTRUMENT MUST BE IN ITS NORMAL OPERATING POSITION TO CALIBRATE THE METER. OTHERWISE, GRAVITY EFFECTS ON THE METER MOVEMENT MAY INTRODUCE SLIGHT ERRORS.

- (1) Set the Amplifier Monitor Select Switch to "OFF".
- (2) Adjust the mechanical zero of the meter as required to set the pointer exactly at "0".
- (3) Adjust the AC signal standard for an output of 1.0 V rms at 400 Hz and connect the output signal to the Model 110 input. If an accurate AC standard is not available, use an accurate AC meter to set the signal generator output to 1.0 V rms and connect it to the Model 110 input.
- (4) Set the Amplifier monitor Select Switch to "F".
- (5) Set adjustment "E" (Meter Cal.) for exactly full scale panel-meter indication.
- (6) Using the DC voltmeter, check that the voltage across the rear-panel Meter Analog Terminals is 1 V $\pm$ 50 mV.

5.7 SELECTIVE AMPLIFIER AND RELATED OUTPUT STAGES

SELECTIVE AMPLIFIER

- (1) Unplug the Model 110 and connect the ohmmeter across R82, a 10 k resistor mounted between one lug of the Set Notch Control and the printed circuit board.
- (2) Adjust the Set Notch Control for an ohmmeter indication of 4.75 k.
- (3) Remove the ohmmeter and restore power to the Model 110.
- (4) Set the Frequency Controls to "10.00", "X10K".
- (5) Supply a 40 Hz sine wave to the input and adjust the input signal level for a panel-meter indication of 0.9 V rms.
- (6) Connect the oscilloscope to the Resonance Output.
- (7) Trigger the oscilloscope from the Model 110 Flat Output. External triggering, although not absolutely necessary, makes many of these

adjustments easier. Because the oscilloscope displays both phase and amplitude information when triggered externally, and because the greatest phase shift per unit adjustment occurs at the point of proper adjustment, one obtains dual confirmation of a proper setting.

- (8) Set adjustment "F" (Low Frequency Balance) for a minimum signal on the oscilloscope (typically 100 μ V peak-to-peak).
- (9) Remove the signal generator and connect a shorting cap to the Model 110 input.
- (10) DC couple the oscilloscope and set adjustment "G" (Output Zero) for as near zero DC output as possible (typically within 50 mV). Alternatively, one could disconnect the oscilloscope and use the DC voltmeter to make the zero adjustment.
- (11) Connect the DC voltmeter to the rear-panel Meter Analog Terminals. The oscilloscope should be connected to the Resonance Output.
- (12) Set the front-panel controls as directed in 5.3, step 4.
- (13) Remove the shorting cap and connect the output of the signal generator (0.9 V rms at 400 Hz) to the Model 110 input.
- (14) Set the Q Selector to "100" and the Amplifier monitor Select Switch to "R".
- (15) Using either method "a" or "b", which follow, adjust the signal generator frequency as required to obtain maximum resonance output. Whether "a" or "b" is more suitable depends on the available test equipment. From the operator's point of view, "a" is usually considered much easier.
 - (a) Adjust the oscilloscope sensitivity and vertical position controls to allow very close examination of either the positive or negative sine-wave peaks. Then adjust the frequency of the signal generator to find the exact point of maximum resonance output.
 - (b) Read the DC voltmeter connected to the Analog Output and adjust the frequency of the signal generator for maximum meter indication.
- (16) Repeat "a" and "b", which follow, until no further improvement is possible.
 - (a) Change the setting of the Q Switch from "100" to "10". Note the exact output indication (oscilloscope or meter monitoring Analog Output).
 - (b) Change the setting of the Q Switch from "10" to "100". Set adjustment "H" (Coarse Notch) to obtain the exact output indication noted in "a".

- (17) Repeat step 16, this time using the front-panel Set Notch Control in place of adjustment "H".

RESONANCE

- (1) Set the Q Selector to "SET NOTCH".
- (2) Set adjustment "I" (Resonance Gain) for a midscale panel-meter indication which drifts as slowly as is possible to obtain. The action of this adjustment is similar to that of the front-panel Set Notch Control as described in Section III.

NOTCH

- (1) Set the Q Switch to "10" and the Amplifier Monitor Select Switch to "F".
- (2) Note and record the DC voltmeter indication.
- (3) Set the Amplifier Monitor Select Switch to "N".
- (4) Monitor the Notch Output with the oscilloscope. Then repeat "a" and "b", which follow, until no further improvement can be made.
 - (a) Change the setting of the Frequency Multiplier from "X100" to "X10K". Then set adjustment "J" (Notch Gain) to obtain a DC voltmeter indication which is the same as that recorded in step 2.
 - (b) Return the Frequency Multiplier to "X100" and set adjustment "K" (Notch Null) for minimum observed signal at the oscilloscope.

ALLPASS

- (1) Set the Amplifier Monitor Select Switch to "A".
- (2) Repeat "a" and "b", which follow, until no further improvement is obtainable.
 - (a) Change the setting of the Frequency Multiplier from "X100" to "X10K". Then set adjustment "L" (0° Gain) as required to obtain the same DC voltmeter indication as was recorded in earlier step 2 of the Notch Calibration.
 - (b) Change the setting of the Frequency Multiplier from "X10K" to "X100" and vary adjustment M (-180° Gain) as required to obtain the recorded DC voltmeter indication.

100 kHz TRIMMING

- (1) Set the Select Switch to "F", the Full Scale Switch to "2V", and the Frequency Controls to "10.00", "X10K".

- (2) Set the frequency of the signal generator to 100 kHz. Then adjust the amplitude of the signal generator output for a panel meter indication of 1 V rms.
- (3) Set the Q Selector to "100" and the Amplifier Monitor Select Switch to "R".
- (4) Adjust the frequency of the signal generator for maximum panel meter indication.
- (5) The panel-meter indication at resonance should be $1\text{ V} \pm 100\text{ mV}$. If the indication is low, trim approximately 1/16 inch from the "gimmick" capacitor C211, which consists of a twisted pair of wires. Repeat trimming as necessary to obtain a reading which is in tolerance. If necessary, re-adjust the signal generator frequency for maximum meter indication. If the initial indication is too high, try twisting the gimmick tighter to increase its capacitance. If this fails, replace the gimmick with one about two inches long, and, after checking that the reading is too low, trim the new gimmick as necessary to obtain the required $1\text{ V} \pm 100\text{ mV}$ meter indication.
- (6) Disconnect the signal generator.

5.8 OSCILLATOR

AMPLITUDE CALIBRATION

- (1) Set the Q Selector to "OSC." and the remaining controls as directed in 5.3, step 4 (page V-3).
- (2) Set adjustment "N" (Osc. Level) for a panel-meter indication exactly two percent over full scale.
- (3) Adjust the red Oscillator Amplitude Control for exactly full scale meter indication.
- (4) Monitor the Oscillator Output Jack with the oscilloscope. The observed signal should be 28 V peak-to-peak sine wave.
- (5) While continuing to monitor the Oscillator Output with the oscilloscope, connect a 600 ohm resistor from the Oscillator Output to ground. Observe that the signal amplitude decreases to 14 V peak-to-peak.
- (6) Set the Oscillator Amplitude Switch to "500 mV" and ascertain that the amplitude of the observed signal decreases to 1.4 V ptp.
- (7) Set the Oscillator Amplitude Switch to "50 mV" and ascertain that the amplitude of the observed signal decreases to 140 mV peak-to-peak.
- (8) Set the Oscillator Amplitude Switch to "5 mV" and ascertain that the amplitude of the observed signal decreases to 14 mV ptp.

FREQUENCY ACCURACY AND OUTPUT REGULATION

- (1) Connect the Frequency/Period Counter to the Flat Output. Use the BNC "T" so that the oscilloscope continues to be triggered from the Flat Output. Set the counter controls to average 10 periods.
- (2) Record the indication of the DC voltmeter, which should still be connected across the Meter Analog Terminals.
- (3) Set the Frequency Controls to "1.00", "X100". The Frequency Vernier should be set to "0".
- (4) Note the counter indication. It should be in the range of 9.990 ms to 10.010 ms. If the indication is out of tolerance, change the value of R65 as required to obtain an in-tolerance reading. Raising the value of R65 increases the counter reading and reducing R65 decreases the counter reading.
- (5) Check the overall frequency accuracy of the Model 110 by using the table on the following page as a guide.

To save time, also check the voltmeter indication at each frequency. The reading should always be within three percent of the value recorded in step 2. From 5 Hz on down, it will be necessary to connect a large capacitor (1000 to 10,000 μ Fd) across the Meter Analog Terminals to stabilize the meter indication. Allow sufficient time for the capacitor to fully charge after each control setting change.

BE SURE THE FREQUENCY VERNIER CONTROL IS ALWAYS AT "0".

5.9 Q CHECK

- (1) Set the Select Switch to "R" and all other controls as directed in step 4 under 5.3 (page V-3).
- (2) Set the counter controls to average 100 periods.
- (3) Connect both the signal-generator output and the input of the Model 110 to the input of the 3 dB attenuator.
- (4) Set the output level of the signal generator to 1 V rms. Then adjust the frequency of the signal generator for a counter indication of 2.5000 ms.
- (5) Monitor the Notch Output with the oscilloscope.
- (6) Adjust the Model 110 Frequency and Set Notch Controls for the best null, as indicated by the oscilloscope.
- (7) Transfer the input of the Model 110 from the input of the attenuator to the output of the attenuator. Note and record the indication of the voltmeter, which should still be connected across the Meter Analog Terminals.

DIAL SETTINGS		COUNTER SETTING	LIMITS
DIGITS	RANGES		
1.00 -----	X1 -----	AVERAGE -----	99010 - 101010
10.00 -----	" -----	1 PERIOD -----	9901 - 10101
1.00 -----	X10 -----	AVERAGE -----	99010 - 101010
10.00 -----	" -----	10 PERIODS -----	9901 - 10101
1.00 -----	X100 -----	AVERAGE -----	99010 - 101010
1.01 -----	" -----	100 PERIODS -----	98296 - 100010
1.02 -----	" -----	" "	97069 - 99030
1.03 -----	" -----	" "	96126 - 98068
1.04 -----	" -----	" "	95202 - 97125
1.05 -----	" -----	" "	94295 - 96200
1.06 -----	" -----	" "	93406 - 95293
1.07 -----	" -----	" "	92533 - 94402
1.08 -----	" -----	" "	91676 - 93528
1.09 -----	" -----	" "	90835 - 92670
1.10 -----	" -----	" "	90009 - 91827
1.20 -----	" -----	" "	82508 - 84175
1.30 -----	" -----	" "	76161 - 77700
1.40 -----	" -----	" "	70721 - 72150
1.50 -----	" -----	" "	66007 - 67340
1.60 -----	" -----	" "	61881 - 63131
1.70 -----	" -----	" "	58241 - 59418
1.80 -----	" -----	" "	55006 - 56117
1.90 -----	" -----	" "	52110 - 53163
1.99 -----	" -----	" "	49754 - 50759
2.00 -----	" -----	" "	49505 - 50505
3.00 -----	" -----	" "	33003 - 33670
4.00 -----	" -----	" "	24752 - 25253
5.00 -----	" -----	" "	19802 - 20202
6.00 -----	" -----	" "	16502 - 16835
7.00 -----	" -----	" "	14144 - 14430
8.00 -----	" -----	" "	12376 - 12626
9.00 -----	" -----	" "	11001 - 11223
10.00 -----	" -----	" "	9901 - 10101
10.99 -----	" -----	" "	9009 - 9191
1.00 -----	X1K -----	FREQUENCY -----	9900 - 10100
10.00 -----	" -----	10 SECONDS -----	99000 - 101000
1.00 -----	X10K -----	FREQUENCY -----	9900 - 10100
1.99 -----	" -----	1 SECOND -----	19701 - 20099
10.00 -----	" -----	FREQUENCY -----	9900 - 10100
10.99 -----	" -----	.1 SECOND -----	108801 - 110999

Table V-1. FREQUENCY TOLERANCES

Note: Sixth digit will not show on five digit counters.

- (8) Transfer the input of the Model 110 back to the input of the attenuator.
- (9) Using the table below, set the Q as indicated. Then increase the frequency of the signal generator until the voltmeter indication is the same as that recorded in step 7. Note the counter indication. If the Q is in tolerance, the counter will indicate some number in the appropriate range shown in Table V-2. First check Q's of 10, 5, 2, and 1. Then set the Q Selector to "100" and repeat preceding steps 4 through 8, after which the Q can be checked at 100, 50, and 20.

Q SETTING	PERIOD LIMITS (ms) FOR RECORDED VOLTAGE OUTPUT
10 -----	2.3770 - 2.3793
5 -----	2.2507 - 2.2733
2 -----	1.9271 - 1.9747
1 -----	1.5094 - 1.5785
100 -----	2.4844 - 2.4896
50 -----	2.4724 - 2.4774
20 -----	2.4352 - 2.4412

Table V-2. Q TOLERANCES

- (10) All Q settings are very stable. However, to achieve a high accuracy ($\pm 1\%$) for the Q of 10, R69, a selected resistor, has been added at the factory. If the period for a Q of ten was too long, increase the value of R69. If the period was too low, decrease the value of R69.
- (11) Disconnect the signal generator, the 3 dB attenuator, and the counter.

5.10 PREAMPLIFIER

GAIN CALIBRATION

- (1) Set the controls as indicated in step 4 of 5.3 (page V-3).
- (2) Set the Q Switch to "SET NOTCH" and adjust the Set Notch Control for a panel meter indication which drifts as slowly as is possible to achieve.
- (3) Reset the Q Switch to "10".
- (4) Monitor the Flat Output with the oscilloscope.
- (5) Connect the Resonance Output to the input of the 10:1 attenuator. Then connect the output of the attenuator to the input of the Model 110.

- (6) Set the Gain Control to "10".

With this arrangement, the gain of the Preamplifier can be adjusted to be as accurate as the attenuator. Connecting the attenuator between the Resonance Output and the Input forms a closed loop with positive feedback. Because both the gain and the attenuation factors are equal, the loop gain will be very nearly one.

As in any amplifier with positive feedback, if the closed loop gain is less than one, the amplifier will not oscillate. If the gain is exactly one, an existing oscillation will continue with no change in amplitude. And, finally, if the gain is greater than one, oscillation build-up will occur until the amplifier commences to clip.

Consequently, the Preamplifier gain can be precisely set by adjusting it for stable oscillation, that is, for a loop gain of exactly one.

- (7) Set Adjustment "O" (X10 Gain) for as stable a panel-meter indication as is possible to achieve.
- (8) Repeating the procedure of steps 5 through 7, use the 100:1 attenuator and a gain setting of 100 to set adjustment "P" (X100 Gain).
- (9) Using the same procedure, use the 1000:1 attenuator and a gain setting of "1K" to set adjustment "Q" (X1K Gain).
- (10) Continuing to use the same procedure, use the 10,000:1 attenuator and a gain setting of "10K" to set adjustment "R" (X10K Gain).
- (11) Unplug the Model 110.
- (12) Remove the left-side cover and remove the screws which secure the Gain Switch Shield. Remove the shield and restore power to the instrument.
- (13) Replace the 10,000:1 attenuator with the 4.95:1 attenuator and set the Gain Switch to "5".

The adjustment for this gain setting is done by selecting the value of R7. Because the gain cannot be easily varied, it will be more convenient to check its accuracy. Then change the value of R7 only if required.

Because the attenuation factor is 1% less than the correct gain, the instrument should be oscillating and the meter should be "pegged" at the full-scale end. Connect a 270 k Ω 10% resistor from the attenuator output to ground to make the attenuation factor 1% higher than the correct gain. After several seconds the oscillation should disappear and the panel meter should indicate zero.

If the instrument performs as here indicated, the gain is within 1% of its proper value and R7 need not be changed. If the meter remained pegged in both cases, R7 would be reduced. If the meter re-

mained at zero in both cases, increase the resistance of R7.

- (14) Use the 1.98:1 attenuator and set the gain to "2". Following the procedure outlined in the preceding step, use the 270 k Ω resistor to determine whether R3, the resistor which sets the gain of two, should be changed.
- (15) Disconnect the attenuator. Then unplug the instrument and replace the Gain Switch Shield, the left-side cover, and the top and bottom covers. Restore power.

5.11 NOISE CHECK

- (1) Set the Model 110 Frequency Controls to "10.00", "X100" and the Q Selector to "100". Then set the remaining controls as directed in step 4 of 5.3 (page V-3).
- (2) Connect the shorting cap to the input.
- (3) Connect the AC voltmeter to the Resonance Output. The average indication over several seconds should be less than 250 μ V.
- (4) Change the setting of the Frequency Controls to "1.00", "X10", and again check that the average meter indication over several seconds is less than 250 μ V.
- (5) Set the Gain Switch to "10K" and the Q Selector to "10". The AC voltmeter indication should average less than 1 mV.
- (6) Set the Frequency Controls to "10.00", "X100". The average meter indication should be less than 2 mV.

SECTION VI TROUBLESHOOTING

6.1 INTRODUCTION

Although the Model 110 is a highly reliable instrument, component deterioration or failure could cause the instrument to no longer meet specifications, or even to become inoperative. Should this occur, a partial or complete alignment (Section V) will generally restore proper operation. In those cases where the malfunction is a result of component failure, aligning the instrument will of course prove to be impossible. For this reason, the following pages are provided. By following the outlined procedures, a person familiar with the operation of the Model 110 should have little difficulty in isolating the problem to a specific circuit. As each step depends on the previous one, it is particularly important that the entire procedure be carried out in the sequence given. Otherwise, the results obtained might easily be misinterpreted, and a normally functioning circuit identified as being faulty.

Once the faulty circuit is located (or before), the user should contact the factory for advice on the relative merits of repairing the unit himself or returning it to the factory for repair. If the instrument is still in Warranty (Section VII), it is especially important that the factory be contacted prior to attempting a field repair, as failure to do so could invalidate the Warranty.

The information provided in this section of the manual is intended only to locate the faulty circuit, and not to identify the specific faulty component. However, information provided in other sections should be useful in troubleshooting further. Section IV contains detailed descriptions of the functioning of each circuit. Voltage and current information is furnished on the schematics at critical points and Figure V-2 (page V-4) shows the location of all circuit board components. Other useful drawings include the two block diagrams (Figures IV-1 and IV-2) and the Chassis Wiring Diagram, page VIII-7. Attention is called to paragraph 6.2, which deals with soldering on double-sided printed circuit boards of the type used in the Model 110. A few minutes study of this paragraph could be of value to those who, although experienced in conventional soldering techniques, have not worked specifically with printed circuit boards.

6.2 SOLDERING TECHNIQUES FOR THE MODEL 110 PRINTED CIRCUIT BOARD

INTRODUCTION

The Model 110 printed circuit board is a two-sided board, that is, there is print on both sides and the holes are all "plated through". As a result, removing components for inspection or replacement requires considerable care to prevent damage to the print. Either one of two methods can be used to remove the solder from a pad. The first entails use of a "solder-sucker" and the second, use of a "wick". Both methods give good results. A brief description of each follows.

METHOD ONE

Removing solder by means of a solder-sucker is a straightforward relatively simple process. The required equipment includes a solder-sucker (UNGAR type SOLDER-OFF #7805 recommended) and a good soldering iron of moderate power (WALL type 14HDG40120 with a type W14KS tip). The specific procedure used depends on whether the component to be removed has bent or straight leads. Most of the components have bent leads. As a result, the solder must be removed from the pad on the side opposite the component and each lead straightened before the component can be removed. In the case of components located directly beneath the Frequency Range Switch, the "opposite" side of the board is not accessible and the solder must be removed from the component side. To make their removal easier, the leads of these components were left straight in the manufacture of the instrument. Appropriate procedures follow.

(1) Bent Lead Components

Heat the pad on the side opposite the component. As soon as the solder flows, use the solder-sucker to remove the solder from the pad. Take care not to prolong the heating any longer than necessary. After the solder has been removed, straighten the lead and, while continuing to apply heat to keep the solder in the hole molten, pull it through the hole from the component side using suitable long-nose pliers. Components which do not move with one lead "freed", such as transistors and trim-potentiometers, can be removed by successively applying heat to each of the leads for a few seconds. Repeat this successive heating until the solder flows in all the holes, allowing the component to be pulled straight away from the board. In any case, after the component has been removed, use the solder sucker to completely clear all solder from the holes.

(2) Straight Lead Components

Heat the lead on the same side as the component. As soon as the solder flows, pull the lead through the hole. When the component has been removed, use the solder-sucker to completely remove the remaining solder from the holes.

METHOD TWO

Wicking entails using a length of stranded wire or shielding braid as a wick to draw up the molten solder from the pad. With this method, exceptionally "clean" work is easily achieved. The equipment required includes a good soldering iron (that recommended above is excellent), a supply of stranded wire or shielding braid, and some rosin base soldering flux. As in the first method, the technique varies according to whether the component has bent or straight leads. Suitable procedures follow.

(1) Bent Lead Components

- (a) Dip a few inches of stranded wire (shielding braid is ideal) into some rosin base soldering flux. Then place the wire on top of the joint to be unsoldered, allowing some of the flux to flow over

the joint. NOTE: Under no circumstances use an acid base flux.

- (b) As shown in Figure VI-1, place a hot soldering iron on top of the stranded wire directly above the joint to be unsoldered. Within a few seconds, most of the solder in the joint will flow quickly up the wick, leaving the joint area free of solder.

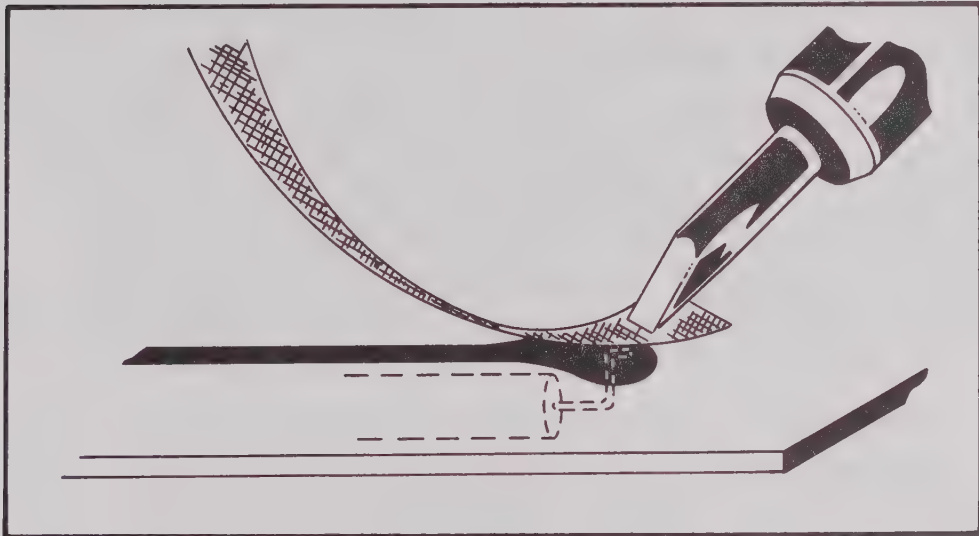


Figure VI-1. SOLDER REMOVAL BY WICKING

- (c) Lift the soldering iron and remove the wick before it freezes to the joint. Cut off the "filled" end of the wick (generally about $\frac{1}{2}$ inch should be removed).
 - (d) Inspect the joint. If any solder remains, repeat the procedure as required. Then straighten the lead and, while applying heat to keep the solder in the hole molten, pull it through the hole. After the component has been removed, use wicking to completely clear all solder from the holes.
- (2) Straight Lead Components

Heat the lead on the same side as the component. As soon as the solder flows, pull the lead through the hole. When the component has been removed, use wicking from the component side of the board to clean the holes.

INSTALLING COMPONENTS

In returning the component or its replacement to the board, make sure the leads are bent on the proper centers and that they don't angle in or out. If they do not pass freely through the centers of the holes, they may catch the edge of the print and lift it. The leads of straight-lead components must be cut before installing the component. In case of bent-lead components, bend

and cut the leads after inserting the component. In either case, solder the leads with a hot iron (no larger than 40 watts) and a good grade of rosin core 60/40 solder. Be sure to apply heat no longer than necessary to achieve a good joint (usually a few seconds). Straight-lead components are, of course, soldered from the component side of the board. Bent-lead components are soldered from the opposite side.

6.3 EQUIPMENT NEEDED

- (1) Oscilloscope, general purpose.

Suggested Instrument: TEKTRONIX type 502A or equivalent.

- (2) DC Voltmeter, 0.1% accurate.

Suggested Instrument: NLS type X2.

- (3) Signal Generator, capable of generating a 400 Hz sine wave at levels from 1 mV to 2.8 V peak-to-peak, using an external attenuator, if necessary, to obtain the lower levels.

Suggested Instrument: HP type 200C.

6.4 PRELIMINARY STEPS

- (1) Remove the covers and check that all of the socketed transistors are properly seated.
- (2) Set the front-panel controls as follows.

Gain -----	1
Gain Variable -----	CAL.
Frequency -----	4.00, X100
Frequency Vernier -----	0
Q -----	10
Amplitude Monitor Select -----	F
Amplitude Monitor Full Scale -----	1 V
Oscillator Amplitude Step Selector ----	5 V
Oscillator Amplitude -----	max. CW

6.5 POWER SUPPLY

- (1) After referring to Figure V-2 for the location of fuses F2 and F3, check that the voltage at each end of F2 is $+32\text{ V} \pm 4\text{ V}$, and that the voltage at each end of F3 is $-32\text{ V} \pm 4\text{ V}$.
 - (a) If the voltages measured are within tolerance, proceed to step 2.
 - (b) If either voltage is present at one end of the fuse only, the fuse is bad and should be replaced. If the newly replaced fuse blows, it will be necessary to find the short circuit.

- (c) Components to be checked if the indicated voltages are absent or out-of-tolerance include: (1) line-fuse (F1), (2) Line-Voltage Selector Switch (and, of course, the line voltage), (3) power supply filter capacitors (C11 and C12), and, (4) the power rectifiers (D1 through D4).
- (2) Refer to Figure V-2 for the location of the -24 V test point and check that the voltage is $-24\text{ V} \pm 0.3\text{ V}$.
- (a) If the voltage is within tolerance, proceed to step 3.
 - (b) If the voltage is high, check the -24 V regulator for proper operation. If low, the problem might be the regulator or a short. To check for a short, unplug the instrument and connect an ohmmeter from -24 V to ground. A normal indication should be about 1 k. In making the measurement, be sure that the polarity of the ohmmeter is such that the diode across the output of the regulator (D511) is reverse biased. If it is forward biased, the measured resistance will mainly be a function of the current supplied by the meter.
- (3) Check that the voltage at the +24 V test point is $+24\text{ V} \pm 0.3\text{ V}$.
- (a) If the voltage is within tolerance, proceed to 6.6 step 1.
 - (b) If the voltage is high, check the +24 V regulator. If low, the problem could be either the regulator or a short. To check for a short, unplug the instrument and connect an ohmmeter from +24 V to ground. A normal indication is about 1 k. In making the measurement, be sure that the polarity of the ohmmeter is such that the diode across the output of the regulator (D512 in this case) is reverse biased.

6.6 PREAMPLIFIER & FLAT OUTPUT AMPLIFIER CHECKS

- (1) Connect the signal generator (400 Hz, 1 V ptp) to the input of the Model 110 and monitor the Flat Output with the oscilloscope.
- (2) The oscilloscope should show a replica of the signal generator output.
 - (a) If the signal is as it should be, that is, a 1 V ptp sine wave, proceed to step 3.
 - (b) If not, the trouble is probably in either preamplifier circuit A1 or in the Flat Output Amplifier.
- (3) Set the Gain Switch to "2". Check for a 2 V peak-to-peak signal on the oscilloscope. Then set the gain to "5". The output signal should be a 5 V ptp sine wave. Finally, set the gain to "10". The observed signal should be a 10 V ptp sine wave.

- (a) If the indicated output was obtained for all settings of the Gain Switch, proceed to step 4.
 - (b) If proper output indications were obtained for only one or two positions of the Gain Switch, the trouble is probably a defective Gain Switch.
 - (c) If improper output indications were obtained at all three gains, check preamplifier circuit A5.
- (4) Reduce the signal generator output to 100 mV peak-to-peak and set the Gain Switch to "100". The oscilloscope should show a 10 V ptp sine wave.
- (a) If the indication is proper, proceed to step 5.
 - (b) If not, check preamplifier circuit A4.
- (5) Reduce the generator output to 10 mV ptp and set the gain to "1K". The oscilloscope should again display a 10 V ptp sine wave.
- (a) If it does, proceed to step 6.
 - (b) If the display is abnormal, preamplifier stage A3 is suspect.
- (6) Reduce the signal generator output to 1 mV ptp and set the gain to "10K". The oscilloscope should again display a 10 V ptp sine wave. It is normal to see noise superimposed on the sine wave at high gains.
- (a) If the display is as indicated, proceed to step 7.
 - (b) If not, preamplifier stage A2 is suspect.
- (7) Turn the Gain Variable Control fully counter-clockwise.

The amplitude of the observed sine-wave should decrease, tracking the control setting, and should reach a minimum of 4 V ptp when the control is fully CCW. This signal is normally noisy. If the indicated behavior occurs, proceed to 6.7. If abnormal indications are obtained, the potentiometer mounted at the rear of the Gain Switch may be defective.

6.7 AC TO DC CONVERTER (METER) CHECKS

- (1) Set the controls as indicated on page VI-2.
 - (2) Increase the output of the signal generator to 2.8 V ptp (1 V rms) and check for full scale panel-meter deflection. Accuracy of the reading will, of course, depend on the accuracy of the signal generator output as well as on the Model 110.
- (a) If the meter indicates full scale, proceed to 6.8.

(b) If not, check the AC to DC Converter.

6.8 SELECTIVE AMPLIFIER AND RELATED OUTPUT STAGES

INTRODUCTION

In addition to a working preamplifier, the Resonance, Notch, and Allpass Output Amplifiers each rely on the Selective Amplifier and, in some cases, on each other, to produce the desired results. It can be seen then, that if a given output is misbehaving the problem is not necessarily in the associated Output Amplifier. The following table has been prepared to help pin-point the malfunctioning circuit. Bear in mind, however, that this is only an aid and is not infallible. Perform the following steps in sequence to obtain the necessary information for the table.

	OK	NOT OK	OK	NOT OK	OK	NOT OK	OK	NOT OK	OK	NOT OK	OK	NOT OK
(1) RESONANCE OUTPUT				✓	✓		✓			✓	✓	
(2) NOTCH OUTPUT			✓			✓	✓			✓	✓	
(3) ALLPASS OUTPUT				✓	✓			✓		✓	✓	
			RESONANCE OUTPUT STAGE		NOTCH OUTPUT STAGE		ALLPASS OUTPUT STAGE		SELECTIVE AMPLIFIER		ALL 4 CIRCUITS OK	

Table VI-1. DEFECTIVE CIRCUIT ISOLATION

RESONANCE

- (1) Set the signal generator output to 1 V ptp and connect the oscilloscope to the Resonance Output.
- (2) Adjust the generator frequency for maximum resonance output. The oscilloscope should display a 1 V ptp sine wave at 400 Hz.
 - (a) If the amplitude is correct but the frequency is wrong, check the wiring and components of the individual Frequency Selector Switches, the Frequency Vernier Control, and the Frequency Range Switch.
 - (b) If the frequency is correct but the amplitude is wrong, first check that the Set Notch Control is properly adjusted, referring to Section III if necessary. If, after re-adjusting the Set Notch Control, the amplitude is still in error, check the "NOT OK" Box next the "RESONANCE OUTPUT". If re-adjusting the Set Notch Control establishes the output at the proper level, check the "OK" Box.
 - (c) If the amplitude and frequency are both incorrect, check the "NOT OK" Box.

- (d) If the amplitude and frequency are both correct, check the "OK" Box.

At this point only one box should be checked.

NOTCH

- (1) Connect the oscilloscope to the Notch Output.
- (2) Tune the signal generator frequency for minimum notch output. This should occur at 400 Hz.
 - (a) If the minimum occurred at 400 Hz, check the "OK" box next to "NOTCH OUTPUT".
 - (b) If the Notch Output did not behave as indicated, check the "NOT OK" box.

ALLPASS

- (1) Connect the oscilloscope to the Allpass Output.
- (2) Trigger the oscilloscope externally so that the phase of the Allpass Output relative to that of the signal generator output can be observed with the oscilloscope.
- (3) Set the signal generator frequency to 4 kHz.
- (4) Note the oscilloscope display. It should show a 1 V ptp sine wave which is in-phase with the signal generator output.
- (5) Slowly decrease the signal generator frequency from 4 kHz to 400 Hz. As 400 Hz is approached, the phase of the Allpass Output should start shifting. At exactly 400 Hz, the Allpass Output should be 180° out-of-phase with the signal generator output. Its amplitude though should remain unchanged.
 - (a) If the indicated results are obtained, check the "OK" box next to "ALLPASS OUTPUT".
 - (b) If the indicated results are not obtained, check the "NOT OK" box.

CONCLUSION

Match the pattern of checks obtained in the previous steps with the example patterns. The circuit most likely to be faulty is indicated below the matching pattern.

6.9 AGC, OSCILLATOR POWER AMPLIFIER CHECKS

- (1) Disconnect the signal generator. Then connect the oscilloscope to

the Resonance Output and set the Q Switch to "OSC." The oscilloscope should display a 2.8 V ptp sine wave at 400 Hz.

- (a) If the output is as indicated, proceed to step 2.
 - (b) If the output is abnormal, check the AGC Circuit.
- (2) Connect the oscilloscope to the oscillator output. Check for a 28 V ptp sine wave at 400 Hz. If the observed signal is abnormal, check the Oscillator Power Amplifier.

SECTION VII WARRANTY

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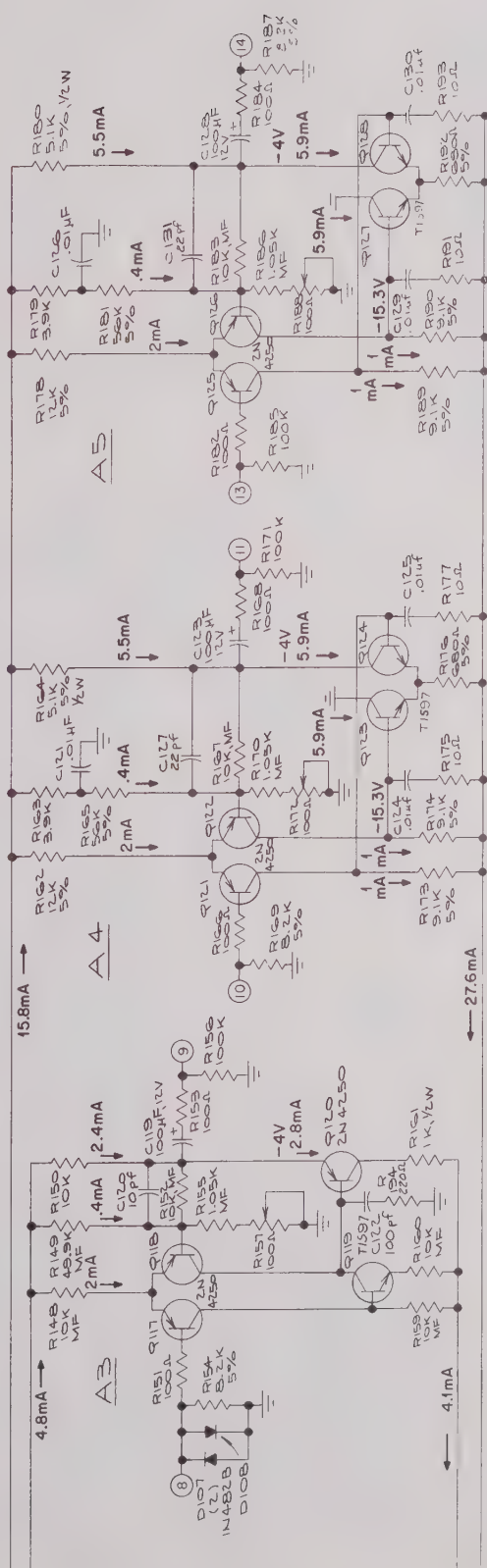
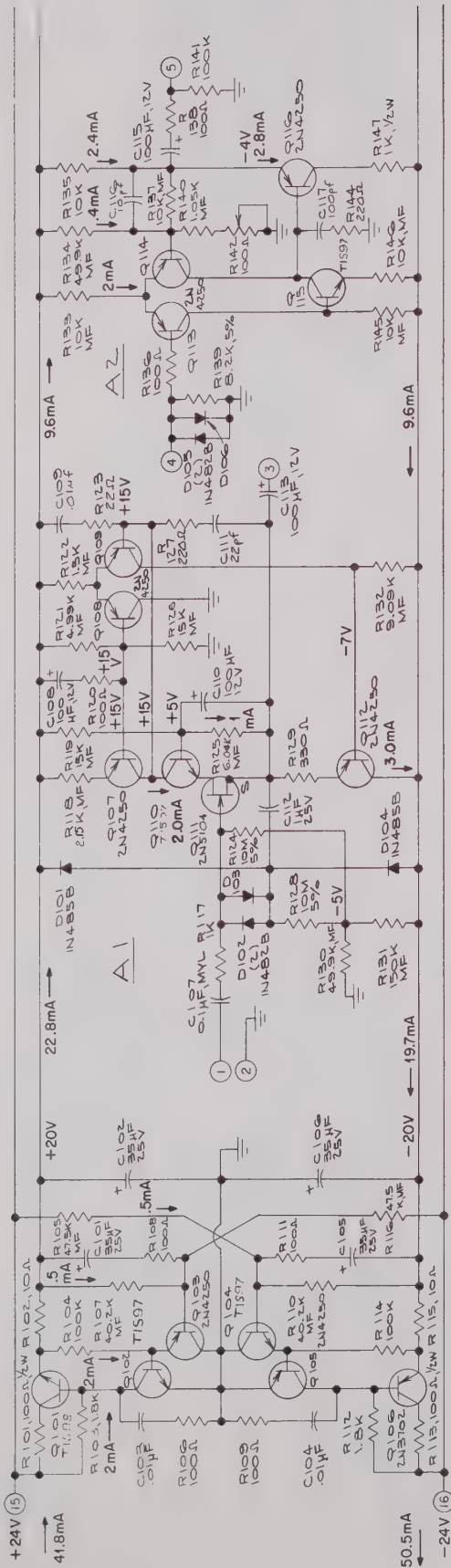
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SECTION VIII
SCHEMATICS

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VIII-1	-----	TABLE OF SCHEMATICS
VIII-2	-----	PREAMPLIFIER
VIII-3	-----	SELECTIVE AMPLIFIER
VIII-4	-----	OUTPUT STAGES
VIII-5	-----	LEFTOVERS
VIII-6	-----	POWER SUPPLY
VIII-7	-----	CHASSIS WIRING DIAGRAM

The voltages indicated on the schematics were measured with the front panel controls set for amplifier operation but with no input signal. The phasor diagrams on the Selective Amplifier Schematic apply with an input signal at the resonant frequency. Waveforms are indicated for the Leftovers Schematic on page VIII-5. These were measured with the instrument operating as an oscillator with the oscillation amplitude controls adjusted for full scale meter indication.

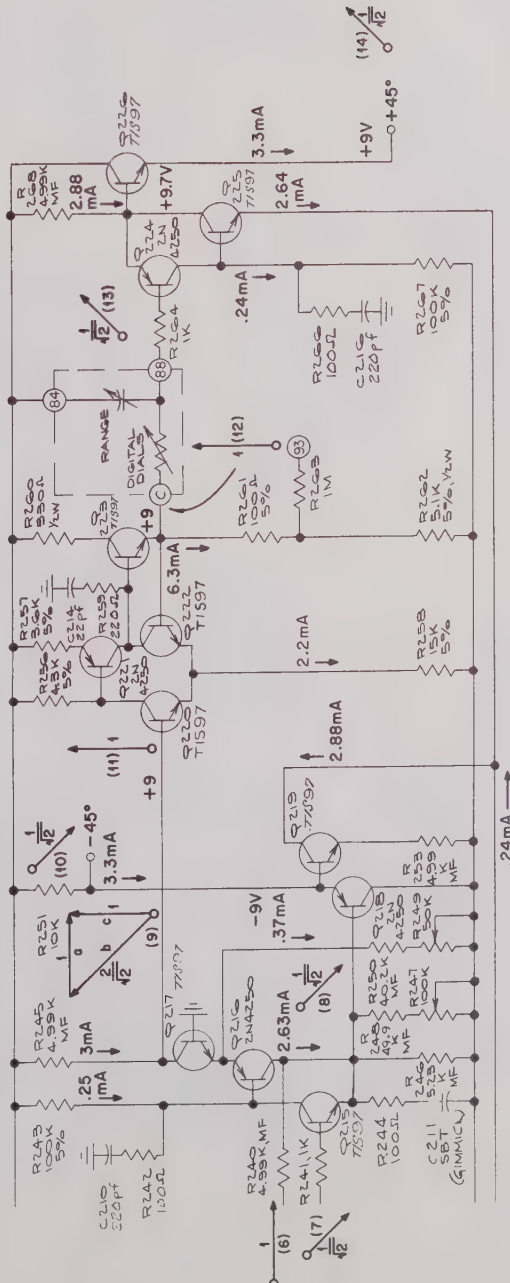
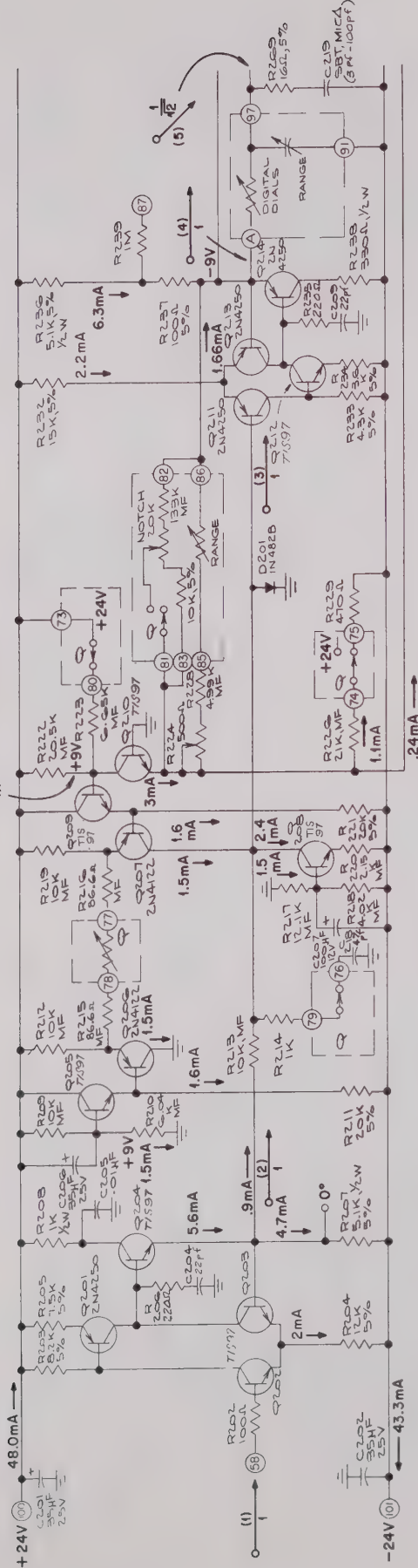


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MODEL 110

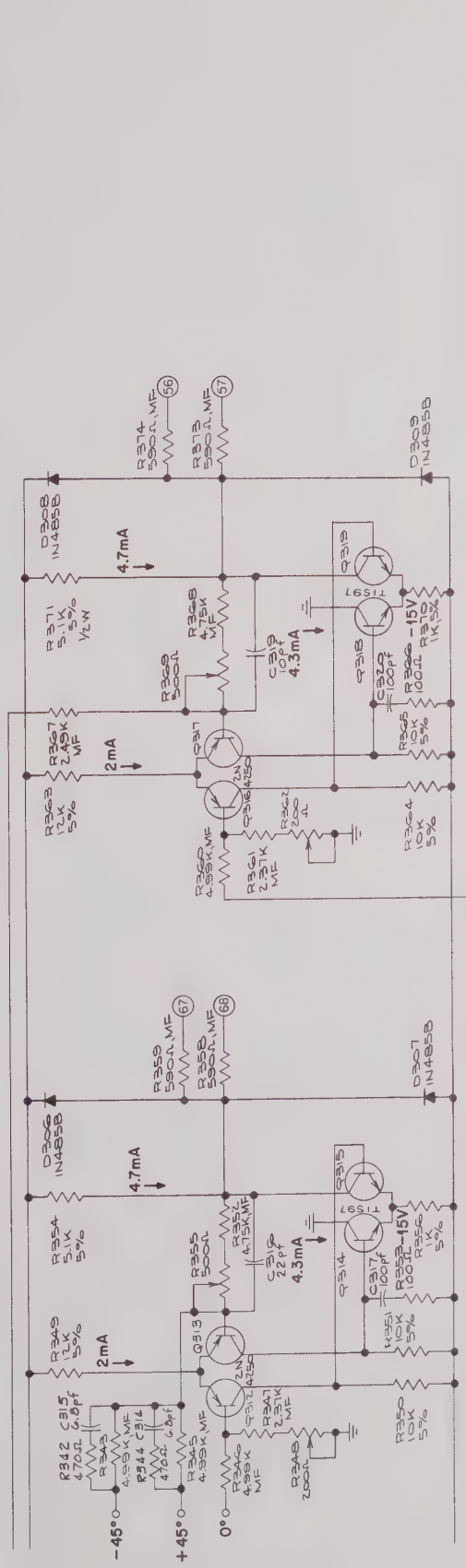
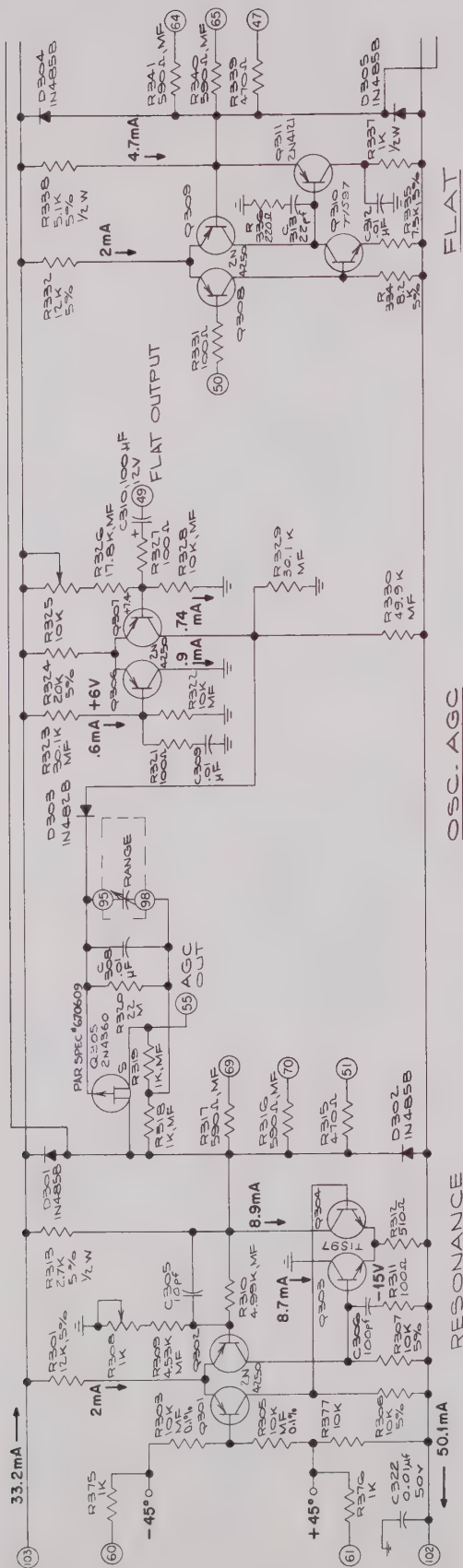
PREAMPLIFIER SCHEMATIC

(15) $\frac{1}{42} K \frac{1}{42} K$ (K = Gain of Q210)

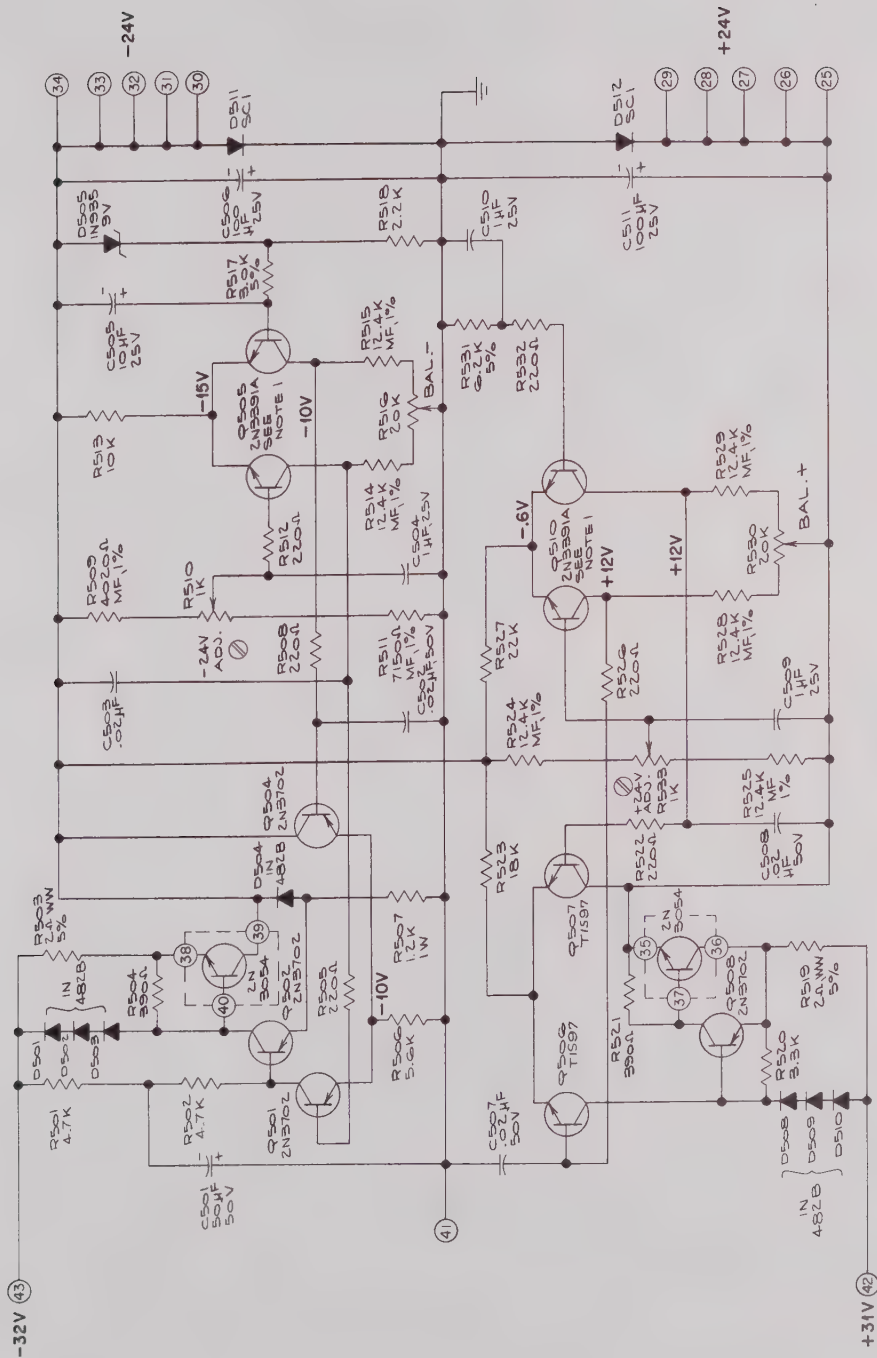


SELECTIVE AMPLIFIER MODEL 110

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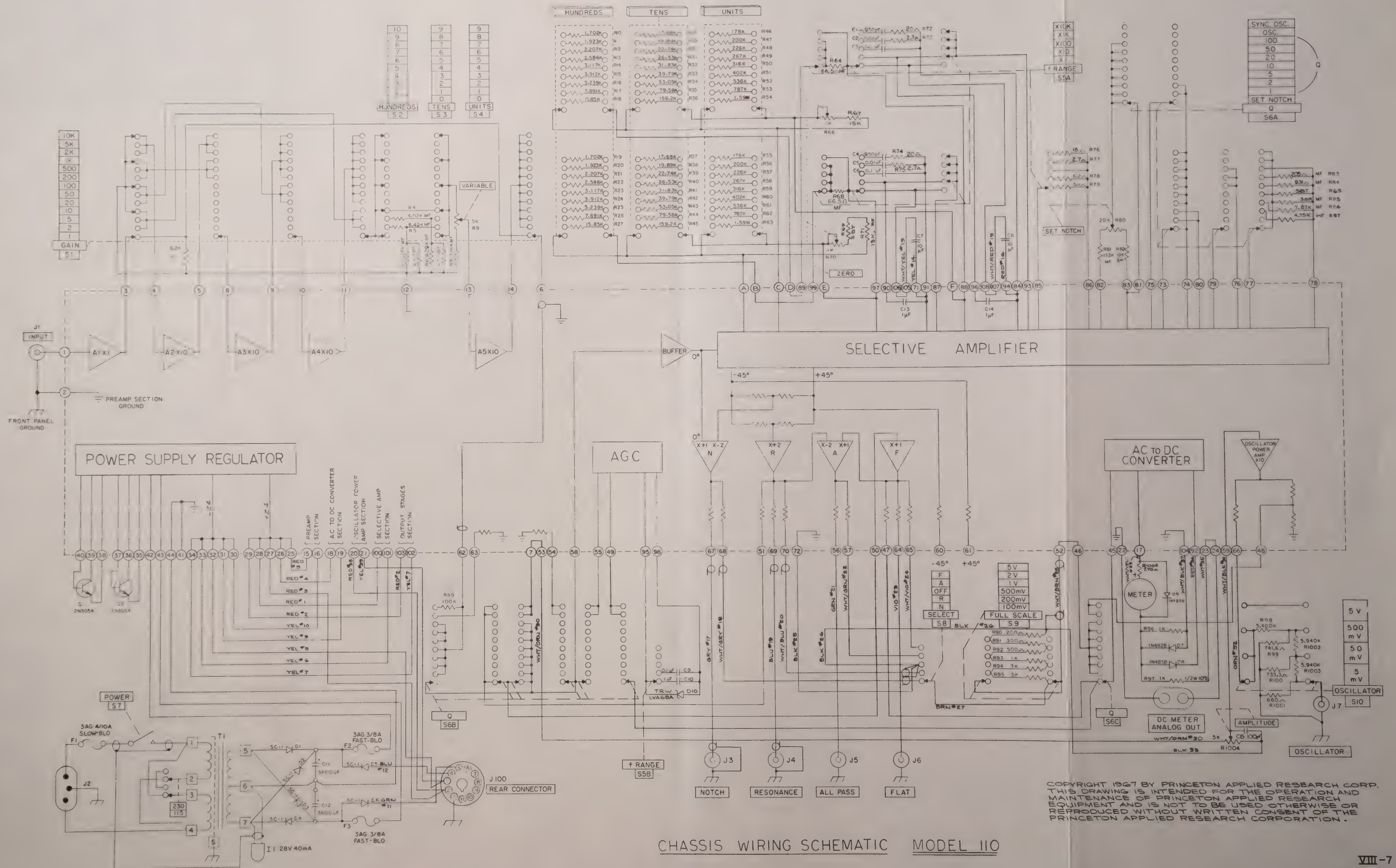
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- NOTES
1. Q505 & Q510 ARE DIFFERENTIAL PAIR & BE MATCHED @ 0.004 (SPEC. 0.004% GREEN).
 2. 2N3711 TRANS. MAY BE SUBSTITUTED FOR 2N3391A TRANS.

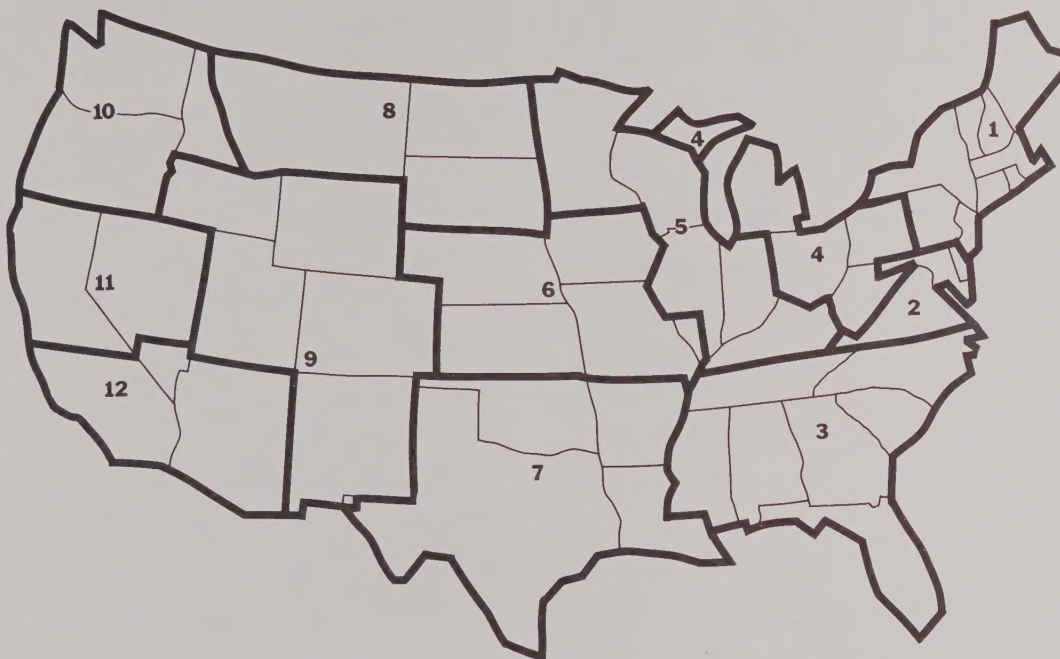
POWER SUPPLY MODEL 110

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